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UNIVERSITY U. of Alberta

DEGREE FOR WHICH THESIS WAS PRESENTED M.Sc.

YEAR THIS DEGREE GRANTED 1973 Fall

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ENVIRONMENTAL IMPACT OF HYDRO-ELECTRIC DEVELOPMENT ON KAKISA LAKE, NORTHWEST TERRITORIES

by

© RAYMOND JOHN LAMOUREUX

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF ZOOLOGY

EDMONTON, ALBERTA
FALL, 1973

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the faculty of graduate Studies and Research, for acceptance, a thesis entitled "Environmental Impact of Hydro-Electric Development on Kakisa Lake, Northwest Territories" submitted by Raymond John Lamoureux in partial fulfilment of the requirements for the degree of Master of Science.

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Date October 1, 1973

ACKNOWLEDGEMENTS

I would like to express my appreciation to Northern Canada Power Commission for making funds available to carry out this study.

Special thanks are due to my tireless field assistants, Dave Christiansen and Joe Weisgerber, without whose knowledge and enthusiasm execution of the field program would have been totally impossible. This thesis is a tribute to their efforts as much as my own.

I would also like to thank my supervisor, Dr. W.A. Fuller and the members of my committee Dr. D.N. Callup and J.A. Nuttall for their help and criticisms.

Numerous people from Canada Department of the Environment were very helpful in supplying background information for the study. I would especially like to thank Mr. Dave Boxer and Mr. Pat Bobinski in this regard.

I would like to offer my heartfelt appreciation to the people of Kakisa Village who were always most friendly and helpful and who made my stay in Kakisa village a time that I will always remember and cherish. Special thanks go out to Jim and Earl McKenzie for their unselfish help and friendship and to Marge Turcotte for her innumerable cups of coffee and her pleasant and always interesting conversation.

I would like to thank my wife Sylvia who helped in a thousand different ways during the field work and who put up with me when I was in the throes of thesis writing.

Sincere thanks are due to those who helped with typing: Gary Bowden of Pearse Bowden and Associates who generously offered to have the first draft typed up in his Vancouver office, the girls in the zoology

office who worked on the tables and Marilyn Westworth who did a fantastic job under difficult circumstances to produce the final draft of the manuscript.

Finally thanks are extended to Dave Westworth who helped in every possible way in the final stages of producing this thesis.

ABSTRACT

A pre-impoundment study of Kakisa Lake, N.W.T., and its surroundings was undertaken from March 20 to October 14, 1972.

The lake was found to be shallow [mean depth 3.8 m (12.4 ft)], warm [18 - 20°C (64.4 - 68°F) in summer], isothermal, near-eutrophic and high in dissolved oxygen (near saturation year-round). Shores were generally rocky and unproductive, but the main, silt-bottomed part of the lake had moderately high standing crops of the large burrowing mayfly, *Hexagenia limbata* and the large tube-building chironomid *Chironomus* sp. Aquatic vegetation was found mainly in the shallows of the east and west ends of the lake. Invertebrate density and diversity in vegetated areas was high.

The lake contained 13 fish species of which walleye was the major commercial species. In addition, pike *(Esox lucius)*, white suckers *(Catastomas commersoni)* and lake whitefish *(Coregonus clupeaformis)* were present in commercially exploitable quantities. The whitefish, however, were so heavily infested with the cysts of the cestode parasite, *Triaenophorus crassus*, as to render them unmarketable. Dwarf lake ciscoes *(Coregonus artedii)* and trout-perch *(Percopsis omiscomaycus)* were the principal prey species for walleye and pike. Standing crop of fish, as measured by "standard gang" catches, was high (mean of 87.6 kg for 29 sets).

A small but highly valued sport fishery, featuring arctic grayling *(Thymallus arcticus)*, was found downstream of Lady Evelyn Falls.

Optimum wildlife habitats were found to the east and west of the lake in the vicinity of slow, inflowing rivers. Habitat suitability for many important wildlife species deteriorated with distance from the lake because of the widespread occurrence of unproductive black spruce muskeg

in areas out of the influence of the lake and its associated streams.

Flooding and raised water table during the growing season should kill most existing willow vegetation and should cause significant mortality to aspen and white spruce along the lakeshore and riverbanks. Damage to tree species would directly reduce food supply and habitat of beavers *(Castor canadensis)*, moose *(Alces alces)*, snowshoe hares *(Lepus americanus)* and red squirrels *(Tamiasciurus hudsonicus)* and indirectly reduce food supply and habitat of other wildlife species.

Increased overwinter fluctuations could cause overwinter mortality of beavers and muskrats *(Ondatra zibethicus)*. High early summer levels would flood many presently-used waterfowl nesting areas.

Greater winter drawdown could reduce spawning success of fall-spawning fish species in some years, but is unlikely to cause total spawning failures in all years.

Higher water levels and greater fluctuation could reduce areal extent and stem density of rooted aquatics, causing some production and habitat losses, particularly for immature and forage fish. Flow-regulation could decrease plankton losses from the lake and thus increase plankton production, partially offsetting production losses related to reduction in rooted aquatics.

The downstream fishery appears vulnerable to construction damage. Recovery, after completion of the project, seems possible if careful flow management is practiced. However, reduced plankton losses from the lake may reduce long-term productivity downstream of the dam.

The large area of land utilized by the local people may lessen the economic impact of wildlife and fisheries damage. However, local people might still suffer considerable loss of enjoyment of their immediate environment as a result of damage to vegetation and wildlife.

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INTRODUCTION

A field study of Kakisa Lake and environs (Fig 1) was undertaken from March 20 to October 14, 1972. The purpose of the study was to assess the environmental impact of a proposed hydro-electric development at Lady Evelyn Falls, some 5 mi (8.1 km) downstream of Kakisa Lake. The area is located in the Northwest Territories at approximately latitude 60° longitude 117°, some 60 air mi (96.6 km) west of the town of Hay River.

The project would involve impoundment of Kakisa River from Kakisa Lake to Lady Evelyn Falls, regulation of the flow of Kakisa River downstream of the Falls and the raising of the average level of Kakisa Lake some 4 to 6 ft (1.22 - 1.83 m) to obtain a dependable live storage of from 6 to 8 ft (1.83 - 2.44 m).

The environmental impact study concentrated on the following matters:

1) Measurement of basic physical and chemical parameters of the lake ecosystem
2) Description of major aquatic and terrestrial plant communities
3) Variations in diversity and abundance of bottom organisms with changes in depth, location and habitat
4) Diversity and abundance of plankton
5) Location and timing of fish spawning runs
6) Feeding habits of major fish species
7) Use of lake area by waterfowl, furbearers, big game and endangered species
8) Patterns of land use by human inhabitants of the area.

Field work concentrated on Kakisa Lake and its inlet streams, the areas where probable impacts were difficult to predict without comprehensive physical, chemical and biological data. Creel census data on the downstream environment was obtained from Fisheries Service, Department of the Environment. In addition, reconnaissance of Kakisa River was undertaken by air and on foot.

This thesis summarizes the findings of the field study and subsequent analysis of collected data and material. As such it is intended to serve as an environmental impact statement for the project.

METHODS AND MATERIALS

Bottom samples, vertical plankton hauls, dissolved oxygen samples and temperature profiles were taken at 30 lake stations and 6 river stations (Fig 2). Water chemistry samples were secured at Stations 1, 2, 3, 4, 6, 18, 21, 26, 28, 29 and 30 and in all of the inflowing rivers (Appendix 1).

Most sampling was carried out during four major periods: before breakup (Mar 27 - May 7); late spring - early summer (June 11 - June 23); mid-summer (July 31 - Aug 11); fall (Sept 24 - Oct 7).

Bottom samples were obtained with a 6 in. x 6 in. (15.2 cm x 15.2 cm) Tall Ekman dredge fitted with a screen to prevent escape of organisms. The Ekman dredge sample was washed in an Ekman bucket with a No. 20 mesh bottom. The residue was preserved in the field in 98% ethyl alcohol and the organisms were separated from the remaining debris in the lab under a dissecting microscope with maximum magnification of 30x. Organisms were later identified, counted and weighed with excess surface moisture removed,on a Mettler Type H6 analytic balance sensitive to 0.0001 g. Molluscs were weighed with shells intact.

Dipnets were used to collect invertebrates from rocky or weedy bottoms where an Ekman dredge was of little use. A strip 5 m (16.4 ft) long by 0.45 m (1.5 ft) wide was swept for each dipnet sample.

Plankton was obtained in vertical hauls from the bottom to the surface with a Wisconsin-type plankton net of No. 25 mesh. The Plankton was washed from the straining cup with concentrated neutralized formalin. Excess formalin was removed in the lab and the sample was washed with distilled water into a 50 ml graduated cylinder. The graduated cylinder was filled to the 40 ml level, stoppered and shaken vigorously. A sample of 1.45 ml was immediately drawn at the 20 ml level of the graduated cylinder with a calibrated pipette and counted on a Wildco plankton counting wheel. The total plankton sample was dried in an oven at 60°C (140°F) and the plankton residue weighed on a Mettler Type Hy analytical balance sensitive to 0.0001 g.

Dissolved oxygen was determined by the azide modification of the Winkler method (American Public Health Association, 1971, pp 477-81).

Water samples were preserved in chloroform (5 ml/l) and analyzed in the water laboratory of the Department of Zoology, University of Alberta.

Soundings were made along a series of transects with a Vexilar "Sound Off" Sonar, accurate to approximately 0.2 m. Positions on the transects were calculated from elapsed times.

Vegetation was mapped using aerial photography coupled with ground information.

Gill nets were set as shown in Fig 2, usually in the vicinity of sampling stations. All nets used were 20 yd (18.3 m) long and approximately 45 in (177 cm) deep. The combination of a 1 1/2 in (3.8 cm) and a 4 in (10.2 cm) gillnet proved the most practical. Other mesh sizes [2 in (5.1 cm), 2 1/2 in (6.4 cm), 3 1/2 in (8.9 cm), 5 in (12.7 cm)] were used early in the study, but were later discontinued.

The stomach contents of fishes were preserved in 98% ethyl alcohol. Food organisms were counted, but were not weighed unless intact. Weights of intact small organisms were estimated from volumetric displacement.

Age-length-weight characteristics of major fish species were derived from raw data of a Fisheries Research Board study carried out on Kakisa Lake in August, 1968.

Invertebrate organisms were identified by keys in Pennak (1953) and Ward and Whipple (1959). Aquatic plant identifications were made using Fasset (1957) and Ward and Whipple (1959).

All field measurements were taken in metric units. However all existing surveys done by others are in English units. In addition, all engineering specifications for the project are in English units. It has therefore been necessary to retain the use of English units for certain data referring to existing surveys and engineering specifications. Topics related to elevations, land areas, and engineering specifications are generally discussed in terms of the English system, with metric equivalents given. However, metric units are used, and English equivalents given, in cases involving lake soundings which were taken in metric units.

GENERAL DESCRIPTION OF KAKISA ECOSYSTEM

Topography and Geomorphology

Land

Kakisa Lake (Fig 1) lies on a plateau between two escarpments, running parallel to the south shore of Great Slave Lake, in a region of Paleozoic limestones. The long axis of the lake is oriented in a west northwest - east southeast direction. For convenience the long shores of the lake will be referred to as the north and south shores, while the shores at the two ends of the lake will be called the eastern and western shores.

The north shore rises moderately to an approximate elevation of 734 ft (223.7 m) above Mean Sea Level and becomes flat. The south shore rises steeply away from the lake towards a high escarpment.

The east shore rises moderately to an approximate elevation of 728 ft (221.9 m) and slopes upward gradually thereafter. The western shore receives three small streams and is extremely low in relief and marshy above elevation 726 ft (221.3 m). Parts of the low-lying land in this area consist of floating sedge peat, especially to the south of River 2. North of this stream, the terrain is firmer and at a slightly higher elevation.

Patterned ground is clearly visible on aerial photography of the study area within a half mile of the western shore and within a mile of the eastern shore. This could be an indication of permafrost conditions in these areas.

Rivers

One major and six minor streams flow into Kakisa Lake (Fig 1). There is only one outflow stream. Salient features of the streams are summarized in Table 1. The Kakisa River, flowing from Tathlina Lake and draining an extensive watershed, is by far the major inflow into Kakisa Lake. The only other stream contributing a substantial inflow is the one locally known as Muskeg River, which is some 30 mi (48.3 km) in length. The other minor streams have small watersheds, which are unlikely to exceed 10 mi^2 (25.9 km^2). For purposes of this thesis, the minor rivers have been given names, as indicated on Fig 1. In addition, the Kakisa River upstream of the Lake will henceforth be referred to by the local name of Tathlina River to avoid confusion with the Kakisa River downstream of the Lake.

Tathlina River, a very turbid river, runs a precipitous course from Tathlina Lake to Kakisa Lake. It has formed a multi-channelled delta where it flows into Kakisa Lake. High turbidities found in Kakisa Lake seem to be largely caused by resuspension of silt entering the lake from Tathlina River.

All other inlet streams are usually slow-flowing and low in suspended silt. However, spring flows in Muskeg River can be considerable. A small delta area at the river mouth is evidence of considerable sediment transport over time.

Muskeg River and Little River have sufficient flow to maintain clean gravels in the channel. In zones of slower flow, these streams have heavy accumulations of silt, plant debris and aquatic vegetation. In late summer these streams are overgrown with rooted aquatics, which encroach upon the channel.

Rivers 1, 2 and 3 are slow-flowing, with soft bottoms of silt and plant debris. Growth of rooted aquatics is extremely heavy.

Campsite Creek possesses well-washed gravels. Summer flow was very low in 1972.

Kakisa River, near the lake, is similar in nature to Muskeg River, with clean gravels in the channel and siltier material in the slackwater areas. Aquatic vegetation near the lake is extremely dense. Downstream of the first bend in the river, the gradient of the river increases, and the river becomes fast-flowing with a rock and gravel bottom free of rooted aquatics. The depth, width and substrate of Kakisa River are similar to those of Tathlina River. However, Kakisa River is less turbid than Tathlina River.

Lake Basin

The basin morphology of Kakisa Lake is simple (Fig 2). Dominant features are moderately-sloping, rocky, littoral zones along the north and south shores and gradually-sloping littoral zones along the east and west shores. Shallow areas predominate over deeper areas (Table 2). The 3 - 4 m (9.8 - 13.1 ft) depth zone has by far the largest areal extent, comprising 34.1% of the total area of the lake. Average depth of the lake on Aug 15, 1972 was 3.8 m (12.35 ft).

The shoreline of the lake is very regular, and the lake is oriented in the direction of prevailing winds. These factors, in conjunction with the absence of wind protection on three sides, give rise to rough wave conditions at most times.

Because of heavy wave action and possibly because of ice action, all shores, except the protected west shore, consist of wave-washed boulders, gravel, or sand down to depths ranging from 1.9 m (6.2 ft) to 3.9 m (12.8 ft) below the 1972 fall water levels of 725 ft (221.0 m) above M.S.L. (Fig 2). The only shallow-water area without a hard bottom is the shallow bay in the west end of the lake which possesses a bottom of organic woody debris.

In most parts of the lake there is a rather abrupt change to a silty bottom. Beyond 4 m (13.1 ft) there is virtually no coarse granular material in the sediments.

By interpolating from the morphometric data of Table 2 and by allowing for the 6 mi^2 (15.5 km^2) of debris bottom in the west end of the lake, the area of the rocky, sandy or gravelly littoral zone can be estimated at roughly 15% of the total measured lake area of 128 mi^2 (332 km^2).

Vegetation

General

Fig 2 shows the location of major vegetation communities in the Kakisa Lake area and Table 3 lists important species.

Aquatic Vegetation

Distribution, abundance and areal extent of rooted aquatic vegetation in both lake and river situations are summarized in Table 4. The outer edges of weedbeds were estimated from observations from a boat.

In the lake proper, aquatic vegetation is largely confined to the shallow eastern and western ends of the lake (Fig 2). Heaviest aquatic vegetation occurs in the outlet region of the lake. There are sparse pockets of aquatic vegetation along the northern shore. The southern shore is almost devoid of rooted aquatics. Aquatic vegetation occurs principally between the depths of 1 and 3 m (3.3 and 9.8 ft), with optimum depth at approximately 2 m (6.6 ft). It is sparse below 3 m (9.8 ft) and non-existent below 4 m (13.1 ft). The chief factors limiting rooted aquatic vegetation appear to be wave action, rocky substrate and high turbidity (which restricts light penetration).

During the summer of 1972 the species *Potamogeton richardsonii* was the dominant macrophyte in the lake, constituting 90% or more of the biomass of rooted aquatics. *Potamogeton pectinatus* commonly occurred interspersed with *P. richardsonii* and often dominated at the outer fringes of weedbeds. On sandy shores exposed to heavy wave action *Potamogeton gramineus* dominated, but was sparse.

The minor inflowing rivers (Muskeg R, Little R, Rivers 1, 2, 3) possess dense and diverse vegetation (Table 3). Dominant species are *Nuphar variegatum* (water lily), *Myriophylum exalbescens* (water milfoil) and *Ceratophylum demersum* (coontail). The latter two species form a virtually continuous cover over the stream beds of Rivers 1, 2, and 3 by late summer. In Muskeg and Little Rivers, plant cover is not continuous, and the gravel bottoms of their channels have a somewhat sparser vegetation.

Emergent Vegetation

The genera *Scirpus* (bulrushes), *Equisetum* (horsetails) and *Carex* (sedges) occupy progressively shallower sites around the lake.

The only large area of *Scirpus* occurs along the shore of the shallow west end of the lake. The only other occurrences of *Scirpus* are in very small semi-protected areas along the north shore.

Equisetum is common along the eastern shore from the outlet region (Kakisa River) to the Muskeg River. A small amount occurs along the lower Muskeg River and larger stands occur along Little River. In the west end of the lake, moderately large areas of *Equisetum* occur in the shallower water just inside the belt of *Scirpus*. *Equisetum* is also common along the banks of Rivers 1, 2 and 3.

Carex is common along the shores of Rivers 1, 2 and 3 and in the large wet meadows between these rivers. It is rather isolated in occurrence in other areas of the lake, occurring in small clumps in association with *Scirpus* or *Equisetum* in slightly protected areas of the north shore, and in small bands along the eastern rivers.

Lakeshore - Terrestrial Vegetation

There are four major zones of terrestrial vegetation around the shores of Kakisa (Fig 2). In the east end of the lake, where topography is flat, there is a diverse vegetational community which includes willow *(Salix* spp), alder *(Alnus* spp), aspen *(Populus tremuloides)*, black spruce *(Picea mariana)*, white spruce *(Picea glauca)* and jackpine *(Pinus banksiana)*. The high diversity of vegetation in this area is likely due to variable drainage conditions which give localized advantages to one species over another. With increasing distance from lake and streams there is a gradual transition to black spruce muskeg, which dominates the larger geographical area.

Along the south shore of the lake, where the land slopes up steeply, mostly sparse shrub vegetation grows within the sphere of influence of raised water levels.

Along the north shore of the lake there is a narrow strip, only one or two trees deep, of mature aspen backed by a slightly wider strip, 200 to 500 ft deep, of mature white spruce. Roots of the first mature aspen trees were at an elevation (Table 5) of 729.5 - 730 ft (222.35 - 222.50 m). White spruce starts at an elevation one or two feet higher than does aspen. Behind the veneer of tall aspen and white spruce lay miles of rather stunted black spruce muskeg.

The western shore of the lake is very low in relief, and much of the region south of River 2 consists of floating sedge bogs. There is a fairly substantial growth of willow over much of the area. In some of the drier spots there is good growth of aspen, and on some ridges, even white spruce. The sedge-willow area gradually gives way to black spruce muskeg toward the west.

Riparian - Terrestrial Vegetation

River bank areas enjoy the dual benefits of better drainage during the growing season and nutrient deposition during spring floods (in the case of reaches possessing flood plains). Thus, even in poorly drained regions, river banks are normally more hospitable environments than the areas they drain.

In the Kakisa area, banks of all the minor inlet streams support good growths of aspen and willow (Fig 2). The banks of Muskeg River are generally too high to support willow, and aspen is the principal riverbank community for the first few miles. Willow is found only on the low ground on the inside of meanders. About 6 miles (15.5 km) upstream white spruce becomes the dominant riverbank species. Little River, with lower banks than Muskeg River has a larger component of willow riverbank vegetation. The low banks of River 1 and the lower reaches of River 2 and 3 are dominated by willow.

The highly incised banks of Tathlina and Kakisa Rivers support good growths of aspen and white spruce. With the exception of the 5 miles (12.9 km) between Kakisa Lake and Lady Evelyn Falls, most of this vegetation would be unaffected by raised water levels.

Good stands of aspen and, occasionally, birch occur around river mouths and on deltaic islands. Spring floods may be responsible for maintaining early successional vegetation in these areas.

The riverbank vegetation of River 1, the lower reaches of Rivers 2 and 3 and Little River also appears to have been maintained in early successional vegetation by high spring water levels. Soil conditions may also have played an important role. The immature aspen vegetation of Muskeg River, however, appears to be a seral stage on the way to a mixedwood (white spruce and trembling aspen) climax. Extensive occurrence of charred 12 inch white spruce logs along the banks bear out this hypothesis.

Physical and Chemical

Climate

The climate of the general area is characterized by cold, long winters, brief, hot summers and rapid periods of transition from winter to summer. Average yearly precipitation (30 yr average) is 12.59 in. (31.99 cm), of which 7.26 in.(18.44 cm) fell as rain and 5.33 in. (13.54 cm) fell as snow (Canada Dept. of Transport, Meteorological Branch, 1968 Records for Hay River, N.W.T.).

Spring Breakup

The small inlet streams became ice-free by the second week in May, 1972. The influx of water from streams appeared to facilitate breakup of the ice sheet on the lake. The ice sheet broke up as follows:

1) A small channel opened up along the shore between Muskeg River and Kakisa River,

2) As breakup progressed a channel opened up along the eastern shore from Tathlina River to Kakisa River.

3) Ice floes broke off rapidly once a channel was established, and breakup of the ice sheet, east of the line between Tathlina River and Kakisa River, took place rapidly. Much of this ice flowed down Kakisa River.

4) The remaining ice sheet to the west broke up rapidly and much of it melted in situ.

In the first three stages of breakup, movement of ice floes down the Kakisa River appeared to be instrumental in the acceleration of breakup.

Water Temperatures

Water temperatures in Kakisa Lake closely approximated average air temperatures with very little lag effect (Fig 3). Although breakup of the lake did not occur until early June, lake temperatures reached summer values [18 - 21°C (64.4 - 70°F)] within two weeks of breakup. The lake was essentially isothermal during the ice-free period (Fig 4).

Temperatures of the minor inlet streams reached as high as 25°C (77°F) during the long summer days. The outlet stream tended to be more stable in temperature because of the moderating influence of the lake.

Lake temperatures plunged from summer levels to 4°C (39.2°F), the temperature of water at maximum density, in the first two weeks of September. It is theoretically possible for ice sheets to form after the water mass reaches a uniform 4°C, given calm air conditions at temperatures below freezing. Actual freezeup occurred October 11.

Winter water temperature profiles (May 7, 1972) were in the form of simple temperature gradients from 0°C (32°F) just under the ice to about 4°C at the bottom (Fig 5). There was no evidence of any large water mass at 4°C.

Dissolved Oxygen

Dissolved oxygen levels were near saturation throughout the year, including winter (Figs 6 & 7). It appears that wave action and photosynthesis kept oxygen levels high all summer. Winter oxygen demands, in the lake proper, were very low. A possible explanation is that high summer temperatures and constant agitation of organic sediments during the ice-free period promoted rapid decomposition, reducing the winter oxygen demand required for bacterial decomposition.

Oxygen levels in zones of organic accumulation, such as Muskeg River, Little River, Rivers 1, 2 and 3 and the bay in the west end of the lake, made heavy winter oxygen demands. Conditions in Muskeg River, Little River and the west end of the lake were found to be winter anaerobic, with high H_2S levels (3 - 5 ppm). However, pre-breakup (April 20) oxygen concentration in Tathlina River was 8.6 ppm (61% saturation)

For a more thorough treatment of dissolved oxygen - temperature relationships of Kakisa Lake, the reader is referred to a paper (Fuller and Lamoureux, 1972) presented at the Western Canada Lakes Symposium (Appendix II).

pH

The pH of the lake water was between 8.6 and 8.8 throughout the study. Sensitivity of the Hellige comparator, used to measure pH was too low to distinguish minor pH cahnges (less than 0.2).

The pH values of the inlet rivers were essentially identical to those of the lake within the limits of accuracy of the method. Values between 8.6 and 8.8 were recorded in all but one instance in early September, when a value of 8.0 was recorded in River 2.

The constant pH of the Kakisa system appears to be the result of the high total alkalinity of the waters, which keeps them well-buffered. The high total alkalinity, in turn, is cerived from the solution of carbonates from limestone formations of the Kakisa watershed.

Turbidity

Turbidity levels in Kakisa Lake were moderately high, and became higher as the season progressed. This can be seen from the decreasing Secchi disk readings (Table 6). Average readings were 2.3 m (7.5 ft) in early June, 1.6 m (5.2 ft) in early August, and 0.9 m (3.0 ft) in September and October. Rawson (1957) noted a similar decrease in Secchi disk readings in five lakes of the Upper Churchill Drainage, where Secchi disk readings declined steadily from a June maximum of 2.5 - 3 m (8.2 - 9.8 ft). He attributed the decrease in transparency to high phytoplankton populations.

In Kakisa Lake, plankton is probably an important consideration in decreasing transparency. However, it is felt that other factors, such as increased winds in late summer and early fall, and lower water levels, exposing larger areas of the lake's silt bottom to wave action, may also be important factors causing increased turbidity from inorganic as well as organic sources. High concentrations of suspended silt were visually apparent in August, September and October, and noticably contaminated plankton samples during this period.

Rawson (1960b) used transparency as a guide to the eutrophic nature of a lake. He cited the fact that the five eutrophic upper Churchill lakes south of the Precambrian Shield had average Secchi disk readings ranging from 1.9 - 3.1 m (6.2 - 10.2 ft), whereas Athabasca and Cree Lakes on the Shield had average readings of 5.6 and 7.8 m (18.4 and 25.6 ft) respectively. He attributed these differences in transparency to differences between the two lake types in standing crop of plankton.

Kakisa Lake, with average summer Secchi disk readings of approximately 2.0 m (6.6 ft) would definitely fall into Rawson's eutrophic category with respect to transparency. However, the value of using transparency as an index of productivity in Kakisa Lake is questionable in view of the large contribution of suspended silt to overall turbidity.

Turbidity in all streams, except Tathlina River was quite low (Table 7) as indicated by Secchi disk readings to the bottom in all but five of the measurements. Secchi disk measurements taken in deep parts of Muskeg and Little Rivers indicated lower average summer turbidity than in the lake. Secchi disk readings taken on the Tathlina River indicated near opacity to light. There was no measurable amelioration of this condition as spring stage declined. Somewhat variable turbidities in Kakisa River suggest that lake storms largely influenced turbidity levels in this outflow stream.

The major source of new fine-grained material appears to be Tathlina River which carries a large silt load into the lake.

Shorelines are generally eroded down to coarse rubble. Since stable vegetation communities are established around the lake, it appears unlikely that much new shoreline erosion has been taking place in recent times.

It is felt that a major source of turbidity in the lake is re-suspension of fine-grained material deposited in lake shallows. It is likely that silt deposited in the mouth of Tathlina River is spread over most of the eastern end of the lake during storms. Settled sediment in the east end of the lake may be resuspended countless times and ultimately distributed over much of the lake bottom. Much of the suspended material may eventually find its way out of the lake system during and after storms. It is certain that storms cause considerable resuspension of sediments from the shallow lake basin, appreciable quantities of which are carried downstream, reducing the rate of sedimentation in the lake.

Color

Kakisa Lake and all of the minor inlet streams were moderately high in color (Table 8). This was likely the result of coloidally dissolved humate (Oden, 1922) from the surrounding poorly drained areas. Some of the lake color may be attributable to iron oxides from surrounding rock formations and to bog iron from surrounding poorly drained areas. Exposed limestone cliffs on the south shore had a characteristic reddish-brown color from oxidation of iron in the rock, indicating measurable iron content in the parent geological material of the area.

Tathlina River is much lower in color than all other inlet rivers, probably because it receives little direct drainage from muskegs and marshes.

Water Chemistry

The striking similarities between the water chemistry of Kakisa Lake and that of Tathlina River (Table 8) suggest that major chemical properties such as total alkalinity, Ca hardness, total hardness, conductance and sulphate are largely controlled by edaphic characteristics of the watershed. Properties such as concentrations of phosphates, nitrates, silicates and iron, on the other hand, are strongly influenced by local biological features of the lake and its surroundings.

The major external source of phosphates for Kakisa Lake is Tathlina River which can carry a heavy orthophosphate load (0.75 mg/1 on June 14, Table 8). Hynes (1970, p 44) stated that the majority of phosphate carried by rivers is adsorbed to particulate matter. It is therefore likely that Tathlina River carries large quantities of phosphorus into Kakisa Lake in its suspended silt and bed load.

A remarkably large concentration (5.20 mg/1, Appendix I) occurred under winter anaerobic conditions in the shallow western bay of the lake. Einsele (1936) found the same phenomenon occurring in the hypolimnion of eutrophic lakes with alternate periods of circulation and stagnation. Under the reducing conditions of stagnation, ferrous iron and phosphate occurred together. Under the aerobic and alkaline conditions of circulation, phosphate was almost entirely precipitated out as insoluble ferric phosphate. Since winter anaerobic conditions in the western bay of

Kakisa Lake reproduce the conditions of stagnation in the hypolimnion of a eutrophic lake, it is reasonable to expect similar processes.

Although impressive amounts of phosphate are produced under ice cover in the western bay of the lake, rapid re-oxygenation of the water likely causes precipitation of much insoluble ferric phosphate prior to utilization by plankton or macrophytes. Thus the phosphate contribution of the west end of the lake to the total lake system may be somewhat less than the high winter phosphate condition might seem to indicate.

Orthophosphate concentrations at other lake stations sampled through the ice ranged from less than 0.05 mg/l (the limit of detection of the analysis technique used) to 0.15 mg/l (Table 8; Appendix I).

In summer, most lake stations, including those in the western bay, had phosphate concentrations less than 0.05 mg/l. Only Station 18 (0.10 mg/l on June 20 and 0.70 mg/l on Aug 2) had orthophosphate concentrations greater than 0.05 (Appendix I).

The large phosphate input from Tathlina River and the exceptional phosphate production in the western bay under anaerobic conditions suggest that the sediments are richly supplied with phosphorus. Concentrations of orthophosphate exceeding 0.05 mg/l suggest at least intermittently high availability of mineral phosphate during the growing season.

Analysis of a timed series of water samples, by very sensitive techniques of phosphorus detection, could shed more light on the dynamics of phosphorus in Kakisa Lake. Simultaneous sediment analysis might also prove fruitful. Sampling times should be spaced closely during the ice-free period when changes occur most rapidly and somewhat farther apart during the iced-over period.

Nitrate levels in Kakisa Lake (Table 8) were quite stable in winter (avg 0.06 mg/l; range 0.05 - 0.07 mg/l: Table 8) and in summer (avg 0.03 mg/l; range 0.02 - 0.06 mg/l). Summer depletion did not occur, suggesting that nitrates are not limiting growth of phytoplankton and, rooted aquatics and that major phytoplankton population fluctuations are not occurring.

Sulfate levels (summer avg 37 mg/l) were high in Kakisa Lake. This ion is of great biological importance in areas of organic accumulation in the shallows of the lake, where large quantities of lethal hydrogen sulfide are produced (3 - 5 ppm). In the western bay of the lake, anaerobic processes were so intense that the sulfate concentration of the water was reduced 90% from the summer level of approximately 40 mg/l to a late spring level of 4 mg/l by anaerobic sulfur bacteria.

Other significant aspects of water chemistry were high silica and iron concentrations. Silica concentration always exceeded the requirements of diatoms, even under bloom conditions. Einsele and Vetter (1938) have shown that a silica concentration of 1.8 ppm in Schleinsee was not depleted by a diatom bloom of 800,000 μ^3/ml. Concentrations of iron greatly exceeded possible unbound levels and suggest complexing of iron with colloidally-dissolved humate as described by Oden (1922). Characteristic iron color was found in small nodules of silt, which form in the silt-bottomed areas of the lake, suggesting involvement of iron in the formation of these silt aggregations. Such concretions were also found by Rawson (1957) in Big and Little Peter Pond Lakes in Saskatchewan, where iron concentration was considered high at 0.06 ppm. In Kakisa Lake the minimum concentration of iron found during the summer was 0.06 mg/l and the maximum concentration found was 4.24, about 70 times higher than the level considered to be high by Rawson.

There are no strong indications that nutrients limit productivity in Kakisa Lake, leading one to the tentative conclusion that physical factors may have a stronger influence on productivity than do nutrients.

In general the water chemistry of Kakisa Lake is quite similar to that of the eutrophic lakes of the Churchill drainage in the sedimentary region of Saskatchewan. These lakes, which include Churchill, Big and Little Peter Pond, Ile a la Crosse, Waskesiu, Otter, Mountain, Nistowiak and Drinking Lakes, were described extensively by Rawson (1957, 1960a, 1960b). The main differences in chemical properties between the preceding series of Saskatchewan lakes and Kakisa Lake would be the significantly higher iron and sulphate levels found in Kakisa Lake. Color was significantly higher only in localized areas of the lake and was not higher for the lake as a whole.

Bottom Organisms

General

For purposes of comparison of bottom organisms, the lake can be divided into three broad zones:

1) Rocky, gravelly or sandy littoral areas devoid of vegetation
2) Vegetated littoral areas
3) Silt-bottomed sublittoral area comprising the entire remaining part of the lake.

Since Kakisa Lake is shallow and lacks thermal stratification, it has no true profundal zone.

For purposes of comparison of bottom organisms of the rivers, the rivers can be classified as:

1) Slow-flowing, with soft bottom and luxuriant growth of rooted aquatic plants

2) Fast-flowing, with rocky or gravelly bottom and few rooted aquatics.

Bottom Organisms of Rocky, Gravelly and Sandy Areas

We were unable to get quantitative dredge samples from rocky gravelly and sandy substrates but non-quantitative dip netting turned up small numbers of leeches (Hirudinea), caddisfly larvae (Trichoptera) and small mayfly larvae (Ephemeroptera). It appears that biological productivity along these shores was low because of unfavorable substrate conditions, which limit burrowing activity, and because of wave exposure, which limits use of the area to species specifically adapted to heavy wave action.

Bottom Organisms of Vegetated Littoral Areas

These areas occur mainly in the shallow, gently-sloping east end of the lake and in the shallow, protected bay in the west end of the lake. In the east end, the substrate is sandy or rocky. Therefore, it is impossible to get quantitative Ekman dredge samples in most locations. In the shallow bay in the west end, the bottom consists chiefly of woody organic debris. Neither the rocky or woody debris bottoms has a large biomass of organisms per unit area. The major biomass of organisms appears to be directly associated with the vegetation.

The importance of aquatic vegetation can be seen in Table 9 which lists the weight and numbers of organisms recovered in a single 5 m (16.4 ft) pass of a dipnet with a hoop width of 0.45 m (1.48 ft) through a heavily vegetated area near shore. This method of collection is extremely inefficient and nets only a very small percentage of the organisms present. Yet 2.21 g/m^2 of organisms were captured as compared to an average of 5.48 g/m^2 of organisms taken by Ekman dredge at standard sampling stations at the same time of year (Table 11). It is unlikely that dipnetting is even 5% efficient in capturing the organisms present, yet weight per unit area taken by dipnet is fully 40% of weight per unit area taken by Ekman dredge in the silt-bottomed sublittoral.

Not only is standing crop significantly higher in the vegetated littoral, but diversity is also much higher. For example, analysis of a single dipnet sample from the vegetated littoral yielded a minimum of 17 species of mayflies, whereas a whole season of sampling the sublittoral turned up only two species of mayflies, one of which was limited in occurence.

Table 9 also illustrates that mayflies must play a key role in the food chains of the vegetated littoral, since they dominate the fauna both numerically and in biomass. The large caddisflies of the vegetated littoral, though much less common in occurence than mayflies, also contribute significantly to the total biomass of organisms.

Bottom Organisms of Silt-bottomed Sublittoral Areas

Silt-bottomed sublittoral areas constitute roughly 80% of the lake bottom. Table 10 lists the bottom fauna encountered. Numbers of organisms in each major group are shown in Table 11, whereas relative weight contribution of each of these groups is shown in Table 12. Generally speaking, *Hexagenia* mayflies make a large biomass contribution relative to their population size. It can also be seen that the combination of mayflies and chironomids accounts for 48.6 to 76.2% of the total weight of fauna. Since the weights given for snails and clams are weights with shells intact, the proportions of total biomass contributed by mayflies and chironomids are therefore considerably higher than even the preceding figures indicate.

The bottom fauna of Kakisa Lake (Table 11) most closely resembles that of Otter Lake in Saskatchewan (Rawson 1970a). Rawson noted that *Hexagenia* mayfly larvae were extremely important in the food chains of the lakes in the Stanley, Saskatchewan area. He stated that they provide a very important part of the food of whitefish, pickerel, pike and perch.

In the lakes of the Stanley area, average summer numbers of *Hexagenia* ranged from 64 per m^2 in Otter Lake to 34 in Drinking Lake. Kakisa Lake, with an early summer population of 78 per m^2 and a mid summer population of 142 per m^2 appears to have a significantly higher population than the lakes near Stanley. Therefore, *Hexagenia* should play at least as important a role in Kakisa as in the Stanley lakes.

In the Stanley Lakes, the large chironomid *Chrionomus plumosus* dominates the chironomid fauna. Although identification cannot be positively confirmed, because emerging adults were not collected, it appears that this species is also the dominant chironomid of Kakisa in 1972, on the basis of the range of this organism in the lakes studied by Rawson.

The main difference between the fauna of Kakisa and the Stanley Lakes is that a high snail population was present in Kakisa, whereas snails are absent from the Stanley Lakes fauna. In addition, the abundance of amphipods (*Hyalella* and *Pontoporeia*) is much greater in the Stanley Lakes than in Kakisa. Finally, the population of sphaeriid clams in Kakisa was roughly double the population in the Stanley Lakes. Differences in faunal proportions between Kakisa Lake and the Stanley Lakes are likely the result of the much greater depths found in the Stanley Lakes.

The crustacean, *Pontoporeia affinis* was frequently found in Ekman dredge samples from Kakisa. In addition the crustacean, *Mysis relicta* was found in the Kakisa River outflow from the lake by D. Musbach, who was studying life cycles of invertebrates in Kakisa River in 1972. Confirmation of the presence of the organism in the lake was made by the discovery of *Mysis* remains in the stomachs of several walleye. However, the organism was never taken in either Ekman dredge or plankton net samples, nor was it commonly found in fish stomachs. This leads one to believe that its density was very low.

The presence of these deep, cold water oligotrophic forms is quite unusual, but not entirely without precedent. Rawson (1957) found very small numbers of *Mysis* in dredgings from the warm isothermal Churchhill Lake in Saskatchewan. However, the writer is unaware of any reports of similar findings of *Pontoporeia* by other workers.

Since the permanent sampling stations set up in the lake tended to favor areas near shore, an effort was made during fall sampling to get sufficient samples from deep parts of the lake for comparison with samples in shallower parts of the lake. It is apparent from results shown in Table 12 that mayflies make up the major portion of biomass in shallow [2.2 - 3.8 m (7.2 - 12.5 ft)] areas, whereas in deeper areas [5.1 - 6.0 m (16.7 - 19.7 ft)] chironomids are the major contributors of biomass.

The situation of differences in dominance of organisms with depth is further analysed in Table 13. Counts of organisms were normalized by the log (x + 1) transformation, as discribed by Elliot (1971, pp 90-92), and densities of organisms from the shallow zones [3 - 4 m (9.8 - 13.1 ft)] were compared with those of organisms from deep zones [5 m (16.4 ft) and deeper].

Hexagenia were classified as small and large, since two very distinct size ranges were present in fall samples. Small *Hexagenia* were generally between 0.2 and 1.2 cm in length, while large *Hexagenia* were generally 2.0 to 3.0 cm in length. It was inferred that most of the large nymphs would emerge the following summer, while small nymphs would require at least one additional summer of growth. Variability of size within the size groups suggests a mixture of 2 and 3 year cycles for the population. Swanson (1967) stated that time to emergence in *Hexagenia* is temperature-dependent, being 1 yr in the south and 2 yr in the north of the United States. It is not unreasonable to suspect that rate of *Hexagenia* development is retarded by the short ice-free season of Kakisa Lake.

Chironomids classified as small belonged to at least 4 species, which generally did not exceed 0.5 cm, and which contributed an insignificant amount of biomass to the total standing crop of bottom organisms. Those classified as large *Chironomus* (probably *Chironomus plumosus)* were from 1.5 cm to 3.0 cm in length. A *Chironomus* species of intermediate size (0.8 - 1.2 cm) was also present in sporadically high concentrations but the distribution of these organisms could not be normalized and they are not included in the analysis. It could not be verified, because of lack of emerged adults, whether this was a separate species or the early instars of the large species. Oliver (1971) stated that most chironomids in substrates in contact with epilimnetic waters have either 1 or 2 cycles per year, depending on environmental conditions. It is therefore quite possible that the large chironomids represent a slower-growing segment of the *Chironomus* population which would complete their cycles in a year, while the medium-sized chironomids may be the second generation of the faster growing portion of the population. Alternative explanations are the possibility of two year cycles for *Chironomus* or the possibility of two morphologically similar *Chironomus* species.

Small *Hexagenia* nymphs were relatively well-distributed over the entire lake bottom, whereas later (large) instars were much more common in the shallows than in deeper areas. The situation for large *Chironomus* was the exact reverse of the situation for large *Hexagenia*,with the greatest density of large *Chironomus* being in the deeper water. Densities of other genera of chironomids (small chironomids) were greater in the shallows than in the deeper areas. Similarly,densities of snails and amphipods were greater in the shallows than in the deep parts of the lake.

It is known that *Hexagenia* mayfly nymphs are capable of migratory movements. Swanson (1967) showed that *Hexagenia limbata* nymphs migrate from their hatching areas near shore to deeper areas in response to overcrowding. He also demonstrated that concentration of nymphs is always greater near shore than in areas distant from shore. This differential is greatest in the fall after the summer hatch is completed,and it is gradually reduced but never eliminated as nymphs migrate into deeper water. The differential in density between deep and shallow areas also occurred in Kakisa. However, it is notable that the differential is greater for the more advanced instars than for early instars. One would tend to infer that the opposite might be the case, since one would suspect that advanced instars would be in a superior position for survival and that the newly-hatched over-crowded instars would disperse.

Low oxygen concentrations are known to be a major cause of mayfly mortality and a limiting factor on depth distribution. Britt (1953) described a massive die-off of the organism in Lake Erie during a temperature stratification caused by unusually calm weather. During this period oxygen levels dropped to the 0.7 to 1.2 ppm range near the bottom, resulting in very heavy *Hexagenia* mortality. Eriksen (1964) determined the absolute minimum oxygen level tolerated by *H. limbata* to be 1.2 ppm. In view of the well-oxygenated and totally-mixed nature of Kakisa Lake mortality caused by oxygen depletion in deeper areas seems only a remote possibility.

Swanson (1967) stated that the 5 - 7 m zone in Lewis and Clarke Reservoir yielded the largest numbers of *Hexagenia* nymphs and that this optimum depth agreed with those found by other workers.

In view of the foregoing, there does not appear to be an obvious environmental reason for the scarcity of large mayflies in deeper parts of the lake. Moreover, *Hexagenia* in all stages of development are found in deep parts of the lake, although numbers are reduced. This would seem to indicate that environmental conditions there are not intolerable for the species.

One possible biological explanation for the lower populations of *Hexigenia* in deeper parts of the lake is competition from *Chironomus*. Both *Hexagenia* and *Chironomus* are burrowing forms utilizing a detritus food source. It is possible that fewer *Hexagenia* survive to late instar stages because the faster-growing *Chironomus* monopolizes the available food supply.

An alternative biological explanation for lower *Hexagenia* populations in deeper water is selective predation on larger nymphs by fish. Thus, large nymphs dispersing into more open habitats in deeper water may suffer very heavy predation while dispersing young-of-the-year nymphs may suffer much less predation.

Snails, amphipods and small chironomid species also show greater abundance in the shallows than in the deep parts of the lake. Snails generally feed on living algae which cover submerged surfaces (Pennak, 1953, p 671). Amphipods are omnivorous and feed on both dead and living plant and animal material of all descriptions (Pennak, 1953, p 436). Chironomid larvae are chiefly herbivorous and feed on algae, higher plants and organic debris (Pennak, 1953, p 649). The presence of aquatic macrophytes and the favorable light conditions for benthic and epiphytic algae should favor amphipods and snails. Small chironomids likely have a much greater variety of available substrates and food sources in the shallows than in the deeper parts of the lake, where environmental conditions are more uniform and competition with *Chironomus* may be intense. It is likely that *Chironomus* does not thrive in the shallows because of a scarcity of suitable burrowing substrate there.

Dry weight of standing crop of organisms in mid summer was 6.58 kg/ha (5.85 lb/a), using Rawson's factor of 1.20 to convert wet weight in g/m^2 to dry weight in kg/ha (Rawson, 1959). Average fall dry weight of organisms for deep and shallow areas (30 samples) is 15.7 kg/ha (14.0 lb/a). These figures could be 10 - 20% high as the result of inclusion of mollusc shells in wet weight determinations. In comparing with the literature of Rawson, who used the average weight of organisms over the period from May 25 to Sept 10, it would be reasonable to use an intermediate value between the mid-summer values (which are likely near-minimum) and the fall values (which are likely near maximum). A rough estimate of 9 - 10 kg/ha (8.0 - 9.1 lb/a) is probably fairly close to an average value of standing crop for Kakisa. This would place Kakisa in the class of La Ronge, Amisk and Ile la Crosse which have standing crops of 8.9, 9.1 and 9.0 kg/ha (7.9, 8.1 and 8.0 lb/a), respectively. Standing crops of Kakisa Lake would be significantly greater than those of the oligotrophic lakes Athabasca, Cree, Wollaston, Reindeer and Frobisher with standing crops of 4.1, 1.6, 4.7, 1.6 and 2.2 kg/ha (3.6, 1.4, 4.2, 1.4 and 2.0 lb/a), respectively.

Bottom Organisms in Slow-flowing Rivers

It can be seen from the partial species list of slow-flowing vegetated streams that this environment produces a higher diversity of organisms than the silt-bottomed part of the lake. No detailed quantitative work on standing crop in vegetated streams has been done but visual examination of the organisms from several 5 m dipnet sweeps indicates standing crops comparable to the vegetated littoral of the lake.

Bottom Organisms in Fast-flowing Rivers

Most of the benthic inhabitants of fast-flowing rivers must be able to hold position in the current and to utilize detritus and epilithic (growing on stones) algal food chains. Fauna of Kakisa River were dominated by nymphs of mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera). Invertebrate collections made by D. Musbach of the University of Alberta indicate moderately high diversity and abundance (pers. comm.). Results of Musbach's study on species composition and life cycles of invertebrates of Kakisa River will be released in a master's thesis which should be completed before the end of 1974.

It is likely that overflow of planktonic organisms from the lake notably increases productivity in Kakisa River by supplying a plankton source of food and nutrients (Hynes 1970, p 256-59). Tathlina River should also enjoy similar benefits from Tathlina Lake, but these benefits may be somewhat attenuated by the time flow reaches the vicinity of Kakisa Lake.

Plankton

The plankton (Table 15) was dominated by copepods and diatoms. Abundance of zooplankters was highest in mid-summer and lowest in fall. Density of copepods did not show a major increase from early summer to mid-summer. However, the cladocerans, *Daphnia galeata mendotae* and *Diaphanosoma brachyurum*, became common in the mid-summer plankton and accounted for the mid-summer increase in plankton density. *Bosmina longirostris* was always present in the zooplankton at low density. Because of its small size relative to the other zooplankters present, it made only a small contribution to total biomass of plankton standing crop. *Leptodora kindti* was observed during cursory preliminary examination of plankton, but was not present in subsamples, indicating low density.

Calanoids were the dominant copepods during early and mid-summer, but a large drop in population had occurred by early October. Cylopoids maintained steady populations throughout the sampling period and were not affected by the fall population drop which drastically reduced all other zooplankters. Thus, they dominated the fall plankton. Cyclopoids overwinter as active forms, whereas other zooplankters form resistent stages.

The calanoid copepods were identified as *Limnocalanus macrurus*, a glacial relict form generally believed to inhabit only deep, oligotrophic lakes. The presence of *Limnocalanus* is consistent with the glacial relict bottom fauna *(Mysis relicta* and *Pontoporeia afinis)* also present in Kakisa Lake. Rawson (1960b) reported that *Limnocalanus macrurus* was present in all but 2 of the 12 lakes studied, including 4 lakes that would be classified as summer-warm, isothermal and eutrophic.

The early summer plankton samples contained a very high concentration of pennate diatoms. The summer plankton contained large numbers of the colonial blue-green alga, *Coelosphaerium* which were clearly visible on the water surface at light bloom density. Fall samples were dominated by diatoms, but density was low.

There is no correlation between density of zooplankters and dry weight of total vertical haul (TVH). In early summer samples, it appears that the large diatom population masks the weight of zooplankters. In the turbid fall samples suspended silt appears to heavily bias dried weights of samples.

Using the summer weight of 13.5 mg/TVH and the efficiency factor of 35% used by Rawson in Cree Lake (Rawson, 1959), the weight of standing crop of plankton would be 34.1 kg/ha (30.0 lb/a) in the deeper parts of the lake. The maximum spring figure would give a crop of 102.3 kg/ha (91.0 lb/a). Conservatively estimating an average standing crop of 50 kg/ha (44.5 lb/a) for the ice-free period would place Kakisa Lake in the same general category as Lac la Ronge, Saskatchewan (64.3 kg/ha (57.2 lb/a)) and ahead of Athabasca, Cree, Wollaston, Reindeer, Frobisher, Hunter Bay and Amisk (36.5, 25.2, 14.8, 28.7, 45, 32 and 32.3 kg/ha (32.5, 22.4, 13.2, 25.5, 40, 28.5 and 28.7 lb/a); respectively).

Fisheries

Fish Species

The lake contained the following fish species:

Walleye	[*Stizostedion vitreum* (Mitchill)]
Pike	[*Esox lucius* (Linnaeus)]
Burbot	[*Lota lota* (Linnaeus)]
White Sucker	[*Catostomus commersoni* (Lacepede)]
Longnose Sucker	[*Catostomus catostomus* (Forster)]
Lake Whitefish	[*Coregonus clupeaformis* (Mitchill)]
Round Whitefish	[*Prosopium cylindraceum* (Pallas)]

Cisco	[*Coregonus artedii* (Le Sueur)]
Troutperch	[*Percopsis omiscomaycus* (Walbaum)]
Spottail Shiner	[*Notropis hudsonius* (Clinton)]
Lake Chub	[*Couesius plumbeus* (Linnaeus)]
Ninespine Stickleback	[*Pungitius pungitius* (Linnaeus)]
Slimy Sculpin	[*Cottus cognatus* (Richardson)]

Ciscoes figure very prominently in lake food chains, as they form a very large, stunted (max. wt. 75 g) population.

A creel census by Fisheries Service, Department of the Environment, confirms that Kakisa River below Lady Evelyn Falls contains Arctic grayling [*Thymallus arcticus* (Pallas)], walleye, pike, and longnose suckers. Slimy sculpins were taken by D. Musbach while collecting invertebrates. It appears likely that a number of forage species that occur in Kakisa Lake would also be present in Kakisa River below the Falls. Lake whitefish are known to run into the lower Kakisa River from Beaver Lake in the fall.

Of the species present in the lake, walleye, pike, white suckers and whitefish are available in commercial quantities. Whitefish, though abundant, are so heavily infested with the tapeworm *Triaenophorus crassus* as to render them unmarketable (Fisheries Research Board, unpublished data). However, they are important to the local economy as dog food. Commercial quantities of whitefish are also taken in the Kakisa River near Beaver Lake in the fall and are used principally for dog food. Grayling, walleye, and pike are game fish in the Kakisa River. Longnose suckers are exploited to some extent for dog food.

Spring and Early Summer Spawning in Kakisa Lake

All species in the lake, with the exception of lake whitefish, round whitefish and ciscoes, are spring or early summer spawners.

Spring spawning was studied only on Muskeg River, as ice conditions prevented us from working elsewhere. The data (Table 16) suggest that most pike had spawned by May 22, most walleye had spawned by May 26, and that most white suckers had spawned some time between May 30 and June 5. The data also suggest that Muskeg River is a major spawning area for walleye, an important spawning area for pike and of somewhat less importance to white suckers.

Monitoring of Tathlina River began after the walleye spawning on Muskeg River had subsided. Thus, no quantitative data exist to document use of Tathlina River by walleye.

Netting around the mouth of Tathlina River yielded several ripe and spent white suckers. The number netted was not adequate to determine the degree of spawning use by white suckers. Circumstantial evidence indicated that Tathlina River was a major white sucker spawning stream, since commercial fishermen tended to avoid fishing the Tathlina River mouth area too early in the season so that they wouldn't have "to pick suckers all day". This would seem to indicate that there is usually a heavy run of spawning suckers into the river just after breakup of the lake. The commercial fishermen said that suckers run into the Tathlina River before the large spring run of walleye occurs. However, they added that the walleye "never have any spawn in them". Netting around the Tathlina River mouth area confirmed that the heavy run of walleye into the mouth of Tathlina River was in fact a feeding run and not a spawning run. It is of course possible that there was a spawning run earlier in the season at about the same time as the run in Muskeg River, and prior to the sucker run on Tathlina River. However, it appears unlikely that, in view of the commercial fishermen's preference for fishing the Tathlina

River mouth area, they would never have come upon a spawning run of walleye in that area in approximately 20 years of fishing the river mouth. Pike, on the other hand, spawn around the mouth of Tathlina River in the two small weedy streams that enter there, as evidenced by the occurrence of young-of-the-year fry. Prey species of walleye and pike also spawn in the Tathlina River mouth area. Ripe trout-perch were virtually the exclusive diet of the large spring run of feeding walleye and pike in the Tathlina River area, indicating that the spawning run of trout-perch must be very large. Further evidence of heavy use of the area by spawning forage fish was our observation, on June 24, of an extremely large number of newly-hatched larval fish, which were field-identified as spottail shiners. In general, it can be said that the environs of the Tathlina River mouth present spawning opportunities for white suckers, pike and probably most species of forage fish.

Little River was not netted during the spring spawning season. However, seining later produced newly-hatched pike fry and 1-year-old spottail shiners. Commercial fishermen indicated that fishing this river during spring spawning runs yields large numbers of white suckers and pike, but few walleye.

The outlet area of Kakisa River had a very large population of young-of-the-year white suckers and a somewhat smaller population of young-of-the-year spottail shiners. The very small size of the white suckers suggested that they hatched in the area and did not actively swim there from another part of the lake. Heavy vegetation, especially along the shoreline, appeared to play an important role in preventing the weak-swimming newly-hatched fry from being carried downstream by the current.

Seining in the three streams in the west end of the lake yielded newly-hatched pike fry, thus proving that those streams are used by pike for spawning. Also, it is probable that walleye use the gravel stream beds of Campsite Creek and of the upper reaches of River 2 for spawning. Because of the distance involved, local fishermen seldom fish the area in the spring. However, they have attempted it occasionally in the past and caught larger than usual walleye in the Campsite Creek area. This may indicate that there is a separate spawning population of walleye in the west end of the lake.

It also appears quite probable that spring and summer spawning fish utilize certain beach areas for spawning since a wide variety of clean substrates exist down to depths ranging roughly from 2 to 4 m (6.6 - 13.1 ft) around the perimeter of the lake. However, wave action may have a large effect on dictating which areas can actually be used by beach spawners

Spring Spawning Below Lady Evelyn Falls

A creel census was taken by Fisheries Service, Department of the Environment, at the campground below Lady Evelyn Falls, the results of which are summarized in Table 17. Because of the small sample size, only tentative conclusions can be drawn. Indications are that spawning of grayling was over by June 3 and possibly earlier. There appears to be active spawning of walleye at least as late as June 9. The pike data are somewhat inconclusive, indicating occurrence of spawning as late as June 4, but with no data during the period from June 5 to June 15. A large spawning run of longnose suckers was observed by the writer on June 3 and on June 5 at the old river ford upstream of the highway bridge.

In general, it can be said that spawning activity of walleye, pike and longnose suckers occurred from one to two weeks later than in the Muskeg River, because of the lag in termperature rise associated with the lake source of the Kakisa River.

To all appearances, the Kakisa River yields a number of favorable spawning areas for gravel spawners along its entire course. It is unlikely that only one spawning areas is used.

Fall Spawning in Kakisa Lake

Heavy catches of whitefish and ciscoes were taken from September 17 to September 20 at four locations (Table 18). Spawning of whitefish commenced on September 19 and was widespread by the following day. Spawning of ciscoes throughout the period was minor. Ciscoes taken just prior to and during the whitefish spawning run were generally not ripe, indicating that the main thrust of the cisco run was probably slightly later than that of whitefish. Spawning runs of whitefish and ciscoes likely continued for many days after sampling stopped.

Although it was not possible to carry out an extensive sampling program, indications are that many miles of shoreline suitable for whitefish spawning occur along the north, east and south shores of the lake. As suspected, the Muskeg River was not used by spawning whitefish, whereas the Tathlina River was. It is concluded that the Tathlina River is the only inlet stream in the system with adequate oxygen to ensure survival of overwintering whitefish and cisco eggs. Its early spring (April 20) oxygen concentration of 8.6 ppm (61% saturation) appears more than adequate for overwinter survival of eggs.

Fall Spawning Below Lady Evelyn Falls

A major whitefish spawning area occurs in the mouth of Kakisa River at Beaver Lake. Indians from Kakisa village make an annual trip to that area and remove approximately 20,000 lb of whitefish, principally for a winter supply of dog food.

Summary of Spawning Use

On the basis of data and indirect evidence presented in previous sections and on the basis of subjective evaluation of substrate suitability during field work, a chart (Table 19), showing estimated degree of spawning use, has been constructed.

Feeding Habits of Fish

i) General. Stomach contents of walleye, pike, ciscoes, white suckers and whitefish were examined in detail. In addition, the stomach contents of a limited number of forage fish and pike fry were examined. Counts were made of each type of organism present in stomachs. Identifications were made to genus when possible. Total weights and volumes of each stomach were taken when possible.

To arrive at an estimate of the original weight of identifiable organisms consumed, average weights of several key organisms were estimated from stomach content weights of intact specimens. Average weight (mg) of key organisms was as follows:

Ciscoes	- 19,000
Troutperch	- 3,800
Nine-spine Stickleback	- 600
Mayfly nymphs (lake species)	- 100
Snails	- 10

Weights of other organisms were estimated by their size relative to key organisms. The final scheme of estimated average weights (mg) per organism are as follows:

Cisco	- 19,000
Troutperch	- 3,800
Nine-spine stickleback	- 600
Walleye, sucker or burbot fry	- 5,000
Unidentified fish	- 5,000
Mayfly nymphs (in lake)	- 100
Dragonfly or damselfly larvae	- 100
Beetle larvae	- 100
Mayfly nymphs (in river)	- 20
Large amphipods (in rivers)	- 20
Caddisfly larvae	- 10
Aquatic hemiptera	- 10
Snails and clams	- 10
Fish eggs (of large fish)	- 10
Small amphipods (in lakes)	- 5
Chironomids,* biting midges	- 1
Cladocerans	- 0.3
Copepods	- 0.1

Although the above scheme has obvious imperfections, it is probably adequate to differentiate important organisms from unimportant ones. When a number of organisms are very nearly equal in importance, the scheme is not sufficiently accurate to rank them in the proper sequence of importance.

Feeding data have been presented in two ways to give a balanced picture of importance of food organisms. The first method ranks organisms in the order of the percentage of stomachs in which the organism occurs. This method overemphasizes the importance of small organisms taken frequently in small amounts. The second method pools the stomach contents of all fish specimens together and estimates the percentage of the total weight that each type of organism contributes. This method probably gives a more accurate picture of the most important food species, but may give large organisms taken infrequently or small organisms taken infrequently, but in large numbers, an exaggerated importance, when sample sizes are small. Because of the biases in both methods of data presentation, the data are presented both ways to convey the information more accurately.

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*small littoral and river varieties dominated feeding.

ii) Walleye. It can be seen that spring feeding inthe Tathlina River mouth was almost exclusively on troutperch (Fig 8; Appendix III). This heavy feeding appears to coincide with a spawning run of large numbers of troutperch into the Tathlina River mouth. Troutperch found in walleye stomachs were found to be in ripe condition. The feeding on troutperch lasted for the entire period (June 4 - 11) the river mouth was fished.

Walleye taken in the open lake in July, August and September showed a marked change to a diet of ciscoes and sticklebacks. No recognizable troutperch remains were found in these stomachs. Although walleye took larger numbers of sticklebacks than ciscoes, the average cisco was more than 30 times heavier than the average stickleback. Therefore, one would conclude that ciscoes were by far the most important forage species for walleye in the open lake during the summer months. Ciscoes would also likely be the most important forage fish on a year round basis for the walleye population as a whole.

Table 20 indicates that smaller fish fed more frequently on invertebrates than did larger fish. Moreover, for small walleye, invertebrate intake contributed a substantial percentage of the total intake of food. The larger fish took only limited quantities of invertebrates, but greatly expanded their intake of fish, with the result that the invertebrate portion of the diet shrank to insignificance.

Of the invertebrates consumed, *Hexagenia* was by far the most common. In view of its large size, this organism likely plays an important role during the first three years of walleye growth.

Attempts to obtain young-of-the-year and one-year-old walleye by seining near shore or by using gillnets were unsuccessful. Those walleye seemed to be widely dispersed and were not easily caught near shore. The situation is probably similar to that in Lake Winnebago described by Priegel (1970). He found that walleye were totally pelagic during their first year of existence. He listed a variety of food items, including copepods, cladocerans, chironomids and fry fish, which were used by walleye less than 175 mm long and showed a progression to larger food items with increasing size. The diet consisted mainly of copepods and cladocerans in the 10 - 50 mm size class and leaned more towards fish in the 101 - 175 mm class. Fry larger than 35 mm were capable of consuming both chironomids and fish fry. If walleye in Kakisa Lake have similar feeding habits, it would appear likely that one and two year old fish, which are generally less than 175 mm, may consume even greater quantities of *Hexagenia* than the three and four year old walleye examined, which ranged in length from 163 to 213 mm.

Examination of the breakdown of fish utilized by walleye for food revealed a sharp increase in feeding on ciscoes as the walleye increased in size. There is no clear trend for other prey species utilized.

iii) Pike. The feeding data on pike (Fig; Appendix IV) show that pike had feeding habits very similar to walleye. Troutperch was the dominant food organism in the spring feeding run at Tathlina River and cisco was the important species in the open lake during summer. Feeding was also analysed in terms of size of the feeding pike (Table 20). Results were similar to those for walleye. Frequency of occurrence of invertebrate organisms decreased with increasing size of pike while frequency of feeding on cisco increased with increasing size. Feeding on troutperch appears to decline with increasing size. Feeding on invertebrates was more diverse in pike than in walleye. Amphipods were taken more frequently by pike than by walleye and frequency of *Hexagenia* was lower. This is probably an indication that small pike congregate in vegetated shallows and slow-flowing streams, where the large amphipod *Gammarus lacustris* occurs in large numbers and where *Hexagenia* is rare.

iv) Ciscoes. Cladocera and copepoda made up approximately 99% of the total intake of ciscoes (Fig 9 ; Appendix V). Both of these organisms belong to the zooplankton. The cisco was the only fish species in the lake deriving its principal nutrition directly from zooplankton. By that token, it should be the fish most efficient in utilizing the energy available in the lake ecosystem. Since it appears to be the principal forage species for walleye and pike, it may be instrumental in the maintenance of adequate growth rates for those species.

The cisco's minor use of food species that are not planktonic suggest that it is capable of using those food sources if the need arises. This flexibility may be important in times of seasonal lows of zooplankton.

At this time, the role of the cisco in perpetuating the tapeworm *Triaenophorus crassus* should be mentioned. The cycle is described in McPhail and Lindsey (1970, p 84-85). The adult tapeworm lives in the intestine of northern pike. In the spring, eggs of the tapeworm are broadcast into the aquatic environment, where they are ingested by copepods of the genus *Cyclops*. When infected *Cyclops* are eaten by whitefish or ciscoes, the parasites encyst in the flesh of those fish. The cycle is completed when a whitefish or cisco is eaten by a pike. Whitefish infestations are normally higher in lakes containing ciscoes. Since ciscoes ingest very large numbers of cyclopoid copepods, their chances of becoming infected are very high. Also, since ciscoes are a preferred food of norther pike, they are instrumental in maintaining infection levels of northern pike at very high levels. Thus, the presence of ciscoes in a lake greatly increases the chances of infections in whitefish by keeping infections in the final host, the northern pike, at high levels.

v) Other Forage Species and Fry Pike. Small collections of trout-perch, spottail shiners, lake chub, sticklebacks and pike fry were examined for feeding (Table 21). Although sample sizes were small, a few conclusions can be made. There is evidence of a progression from copepods to cladocerans to small insect larvae and adults with increase in size of fry. It also appears that larval stages of a wide variety of small insects were the preferred food for adult forage fish. It is interesting to note that piscivorous habits were established very early in the life of a pike. Fig 26 lists a burbot in the stomach of one of the pike fry. The pike fry in question measured only 3.9 cm while its prey measured 1.5 cm.

vi) Whitefish. Examination of the feeding data for whitefish caught in or near rivers (Fig 11; Appendix VI) indicates a major preference for mayflies (Ephemeroptera) and a secondary preference for cladocerans, amphipods, water bugs (aquatic Hemiptera), and aquatic beetle larvae

(Coleoptera). In the open lake, major feeding effort was concentrated on fewer organisms, with snails (Gastropoda) the most important items and mayflies and clams (Pelecypoda) the major secondary items. The large component of fish eggs in the diet was probably an artifact of the data, resulting from the fact that a large proportion of the whitefish were taken during their spawning season, when whitefish commonly ingest their own eggs.

It should be noted that feeding was balanced more evenly over a wider variety of organisms in rivers than in the lake, due to availability of a wider variety of organisms.

vii) White Suckers. Of a total sample of 50 white suckers examined, all but one were taken in or near river mouths. During the field season only a few specimens were taken in the open lake, indicating that white suckers exhibit a definite preference for river and river mouth habitats in Kakisa Lake.

The range of invertebrate organisms consumed by white suckers was very similar to that consumed by whitefish (Fig 12; Appendix VII). In comparing the fish of each species caught in or near streams, it can be seen that mayflies appear to have been the most important food organism for both species, with very similar levels of consumption. However, chironomids also appear to have been a very significant food item for white suckers, whereas they were a rather insignificant portion of the whitefish diet. Conversely, intake of cladocera appears to have been much less in white suckers than in whitefish. Feeding on snails, clams and caddisflies appears somewhat higher in white suckers than in whitefish in rivers. In general, white suckers tended to have a stronger secondary preference for sedentary organisms than did the whitefish.

Growth Rates

Data supplied by Fisheries Research Board, Department of the Environment (Fig 13; Appendices VIII - XI) show that pike from Kakisa Lake reached spawning size (about 600 g) after 3 or 4 summers of growth. Walleye on the other hand, did not normally reach spawning size (about 500 g) until they had completed 8 or 9 summers of growth. The growth rate of whitefish, like that of walleye, was fairly slow when compared to pike. Whitefish usually reached spawning size (700 - 800 g) in 8 or 9 summers. Growth rates of white suckers were comparable to those of pike for the first seven summers of growth. White suckers usually reached spawning size (700 - 800 g) in 5 or 6 summers. Minimum spawning sizes for the various fish species were deduced from weight and sexual maturity data from the present study.

Comparisons with Growth Rates in Other Lakes

Table 22 gives growth data of walleye, pike and whitefish of other western and northwestern lakes from studies by Rawson (1951, 1953, 1957, 1959) and Kennedy (1953). It can be seen that walleye grew appreciably faster in the oligotrophic Wollaston Lake and in the mesotrophic Lac La Ronge than they did in Kakisa. In the oligotrophic Great Slave Lake growth rates of walleye were much slower than in Kakisa in the 1 - 5 year class and somewhat faster than in Kakisa in the 5 - 10 year class. By the eleventh summer walleye were about the same size in both lakes. The highly eutrophic Big Peter Pond Lake, like Kakisa, had growth rates significantly lower than those of la Ronge and Wollaston.

Maximum sizes of fish taken in the present study were 1600 g for walleye, 6700 g for pike, 2250 g for whitefish and 1700 g for white suckers. Maximum weight of walleye netted compares closely with the heaviest walleye (1771 g) taken during the 1958 FRB study (Appendix VIII). Maximum weights of pike, whitefish and white suckers in the present study were significantly greater than the FRB maximum weights of 1839, 1074 and 1180 g for the three species (Appendices IX - XI).

Pike in their first two years of growth in Kakisa Lake had slightly higher growth rates than in Lac la Ronge and much higher growth rates than in Wollaston, Great Slave and Otter Lakes. Growth of pike in Lac la Ronge was much higher after the second summer than in Kakisa, so that by the eighth summer Lac la Ronge pike were double the weight of Kakisa pike. However, growth rates of Kakisa Lake pike greatly exceeded those of pike in Great Slave Lake (oligotrophic), Wollaston Lake (oligotrophic) and Otter Lake (eutrophic).

Whitefish in Kakisa Lake had better growth rates than in Lac la Ronge and Great Slave Lake, slightly poorer growth rates than in Big Peter Pond Lake and much poorer rates than in Wollaston Lake.

In general findings of the present study support the contention of Rawson (1960b) that growth rates of fish are not useful indicators of productivity in lakes. The most productive lake Rawson studied was Big Peter Pond Lake (Rawson 1957, 1960). Growth rates in that lake were among the lowest of the lakes he investigated and comparable to those found in Kakisa. Yet, the plankton, bottom organisms and fish standing crops which Rawson used as indicators of productivity were much higher in that lake than in any of the other lakes studied. One might conclude from this that large populations of fish in productive lakes may have lower growth rates than low populations in unproductive lakes.

There appears to be a notable lack of large old fish in Kakisa Lake when it is compared to the other lakes previously mentioned. The most likely reason for this phenomenon may be the commercial fishing regulations that were in force until 1965. Those regulations permitted 250,000 lb of walleye to be caught every five years. There was no stipulation as to how quickly that amount of walleye could be taken from the lake. Consequently, large commercial operators would move in and remove the entire 5 year quota within a period of a few weeks. The 4 1/2 inch mesh nets used were probably very efficient in depleting a large proportion of the population of walleye larger than 500 g. Since the walleye fishing effort tends to be non-selective as to species it is likely that considerable numbers of large pike, whitefish and white suckers were also removed. This heavy selection against large fish probably created an unbalanced population structure in which greater than normal numbers of small and intermediate sized fish were able to survive to maturity, resulting in a population of stunted individuals.

Variation of Fish Size with Location

Table 23 shows the breakdown in body weights of the major large species for various regions of the lake.

It can be seen that no pike less than 100 g were taken outside of the vegetated areas of the lake. Pike larger than 1000 g, on the other hand, ranged freely through every region of the lake.

Walleye less than 100 g were found almost exclusively in the eastern half of the lake, in or near aquatic vegetation, in the shallow open water area, and close to the north shore. Thus their distribution corresponded with the vegetated littoral area together with the parts of the shallow open-water area that were optimum habitats for *Hexagenia*. Larger walleye (100 - 999 g) had a more general distribution although heaviest concentration still occurred in the east end and along the north shore. Walleye over 1000 g tended to be quite evenly distributed throughout all lake regions, although none were netted in the weeds in the west end.

The greatest number of whitefish under 100 g were taken in the weedy shallows of the east and west ends. There was also slight evidence of congregation of young fish near the north and south shores.

White suckers less than 100 g were found mainly in the east end and along the north shore. Adults were also strongly confined to the eastern and northern shores. Only individuals larger than 1000 g were found outside those areas.

There is a consistent trend to close association of juveniles of all species with the heavily vegetated eastern and western shores. There is also a trend of association with the more lightly vegetated north shores and with the eastern shallows. All the previously-mentioned areas are the more productive areas of the lake for bottom organisms. In addition, they are adjacent to spawning streams as well as to probable shore spawning areas. For these reasons, those areas are likely the optimum rearing habitats for both invertebrate-feeding and piscivorous fish. The high invertebrate densities in those areas likely favor walleye and pike by both attracting prey species and by directly providing an important part of their diets during early development. In addition, vegetation cover may also be important to protect juvenile fish of all species from attack by very large adult predators.

Productivity of Kakisa Lake

Rawson (1960b, 1961) summarized his studies of Saskatchewan lakes by analysing the physical and chemical variables indicative of high productivity. He found that productivity increased with decreasing mean depth, with increasing mean temperature in the first 10 m of water, with decreasing transparency, with decreasing bottom oxygen (July - August) and with increasing total dissolved solids. He devised a scoring system in which the ranks that the lake held in each one of these categories were added together to form a "physical score". The scheme of Rawson has been adapted in Table 24 to include Kakisa Lake. The inclusion of Kakisa increases the possible score in each category from 13 to 14 and thus slightly changes the original scores calculated by Rawson.

On the basis of "physical score" Kakisa would be more productive than any of the Saskatchewan lakes studied by Rawson. An effort was made to determine whether this high "physical score" actually indicates high biological productivity. In his comparative study, Rawson used weight of net plankton per unit surface area, weight of bottom organisms per unit surface area and weight of fish per "standard gang" (50 yds each of 1 1/2, 2, 3, 4, 5 and 5 1/2 in. mesh gillnet) as biological indicators of productivity. Summing the ranks of the lakes in each category gives a "biological score".

The average standing crop of bottom organisms in Kakisa Lake has been estimated at 9 - 10 kg/ha in a previous section, in the general range of Lakes La Ronge, Amisk and Ile la Crosse. The conservative assumption that the average standing crop is just slightly lower than any of the above mentioned lakes would give Kakisa a score of 7 in Table 24.

Average "standard gang" catch for Kakisa had to be estimated indirectly because it was impractical to set full standard gangs during the study, due to manpower considerations. However, records of the FRB 1968 (Table 25) study made it possible to calculate that the standard gang catch averaged 2.87 times the catch from 50 yds of 1 1/2 in. and 50 yds of 4 in. mesh net. Since 20 yds of 1 1/2 in. and 20 yds of 4 in. mesh were used, equivalent "standard gang" catch should be roughly equal to 2.87 x 50/20 x actual catch or 7.175 x actual catch. Actual catch and equivalent "standard gang" catches are shown in Table 26. The average equivalent "standard gang" catch weight for 29 net sets is 87.6 kg. This would give Kakisa Lake a 13 score in this category, with only Big Peter Pond Lake having a higher catch at 127 kg.

Average standing crop of plankton has been estimated to be in the range of Lac la Ronge in a previous section. Conservatively estimating that the average standing crop in Kakisa is slightly less than in La Ronge gives Kakisa a score of 8 in Table 24.

The overall "biological score" of 28 places Kakisa in a category somewhere between that of the eutrophic glacial drift lakes of central Saskatchewan and the mesotrophic lakes along the margin of the shield.

On the basis of its physical and chemical properties, it might be expected that Kakisa would have a higher biological score than Big Peter Pond which Rawson (1960b, 1961) considered the most productive of the lakes studied. However, there are at least two reasons why annual production may be lower. Big Peter Pond lies approximately at latitude 56°, roughly 5° further south than Kakisa. Consequently, the ice-free period is about 6 weeks longer. In addition, the flushing time of Kakisa is only about 1.1 years as compared to 12.5 years in Big Peter Pond.

Rawson (1960b) discussed the effect of flushing time on the lakes of Saskatchewan. He postulated that the 9 month flushing time of Ile la Crosse Lake is responsible for the loss of newly-formed plankton before it can be fully utilized, resulting in greatly lowered productivity. He notes that, although Ile la Crosse had the highest "physical score" of all the lakes south of the Shield, it had the lowest "biological score".

In summary, it can be said that Kakisa Lake is an isothermal, non-stratified, near-eutrophic lake, which is productive for its latitude. It is also subjected to rapid flushing which may reduce productivity to a level below its edaphic and morphological potential.

Waterfowl and Shorebirds

Spring

In the spring, the principal waterfowl area is in the region of the outlet (Kakisa River). This area remains open all year round and is the only area available to waterfowl in the month of May. Because of the luxuriant growth of vegetation in the summer, there is still abundant spring feed in the form of winter buds, roots, seeds, and invertebrate organisms. Moreover, the river at this time is shallow and utilizable by both dabbling and diving ducks.

The entire stretch of open water from Lady Evelyn Falls to the lake proper is used by waterfowl in the spring.

It was difficult to get an exact count of waterfowl in the outlet region because birds were constantly disturbed by human activity. Maximum numbers of ducks observed at one time was 250. Assuming a 50% efficiency in sighting, this would place the number of ducks at approximately 500. It is very difficult to estimate how many ducks used the area over the entire spring season.

More than half the ducks sighted were mallards *(Anas platyrhynchos)*. The remainder were about equally divided between buffleheads *(Bucephala albeola)* and common goldeneyes *(Bucephala clangula)*. Very small numbers of pintails *(Anas acuta)*, green-winged teal *(Anas carolinensis)*, lesser scaup *(Aythya affinis)* and shovelers *(Spatula clypeata)* were sighted. In addition, 27 American widgeons *(Mareca americana)* were spotted on one occasion.

Numerous Canada goose *(Branta canadensis)* flights were observed from April 24 to May 7, but landings were observed on only two occasions. Flocks of feeding whistling swans *(Olor columbianus)* were observed on May 9 and May 13, numbering 12 on the former date and 40 on the latter. At least 250 spotted sandpipers *(Actitis macularia)* and lesser yellowlegs *(Totanus flavipes)* fed heavily on exposed mud flats in the outlet area prior to the late May rise in lake level.

Summer Breeding Season

Good nesting areas for ducks were confined principally to the low lying land at the eastern and western ends of the lake. Because of the rocky exposed shores of the lake and scant emergent vegetation, nesting areas for dabbling ducks along the lakeshore proper were few, except along the shore of the west end of the lake. The majority of nesting sites for dabbling ducks were located along the slow inflowing streams in the east and west ends of the lakes and in the area of small potholes just west of the lake.

During the summer months diving ducks were commonly sighted on the lake. Abundance was not exceptionally high. These diving ducks were principally goldeneyes *(Bucephala clangula)*, lesser scaup *(Aythya affinis)* and surf scoters *(Melanitta perspicillata)*. Of these species the goldeneye is a tree nester while the others are groundnesters. As with dabbling ducks, the best nesting locations for these ducks were along the slow inflowing streams and in the marshy areas west of the lake.

An attempt was made to estimate the numbers of pairs of nesting ducks in various areas around the lake on the basis of observed densities of ducks in the Peace-Athabasca Delta area (Peace-Athabasca Delta Project Group, 1973, pp 64-67) for roughly similar habitats. Data on waterfowl habitat in the Peace-Athabasca Delta are in terms of miles of lake shoreline. In Kakisa, much waterfowl habitat is along slow-flowing streams and equivalent lake shoreline was estimated at twice the length of mainstem streams. The accuracy of such a conversion is questionable. However, the estimation method seems preferable to a totally subjective approach.

It is estimated (Table 27) that the Kakisa Lake area contains approximately 300 pairs of nesting waterfowl of which approximately 85% are dabblers and 15% are divers.

An estimated 70% of the total duck population nests in the west end of the lake which appears to be the only suitable nesting habitat of diving ducks and the preferred nesting habitat of dabblers.

Spotted sandpipers, which are solitary birds, were well-distributed around the lake and up the inlet streams during summer months. The fact that they were everywhere in evidence indicates high populations of nesting birds.

A nesting colony of approximately 200 California gulls was found about two miles up Tathlina River on a rock island in the middle of the river.

Late Summer and Fall

Kakisa Lake received moderate to heavy use as a late summer and fall staging area.

Intensive duck activity in the outlet area commenced in early August when one to two hundred pintails moved in and fed heavily on the dense growths of potamogetons. As the season progressed, other dabbling ducks moved in, notably mallard, teal, widgeon, and gadwall. With the advent of cold weather in September, the number of dabbling ducks decreased, and the number of diving ducks increased. Large numbers of goldeneye were present in September, numbering about 500 at their peak. In addition, small numbers of white-winged *(Melanitta deglandi)* and surf scoters were present. There was also fairly heavy duck activity around most of the inlet streams and in the western end of the lake. Total number of ducks using the lake at any one time was not likely greater than 2000, but total number using the lake throughout the fall season was impossible to estimate.

Geese and swans were more numerous in the fall than in the spring and duration of stay was longer. The two points on the west end of the lake were the principal areas used by geese. Occasional flocks were also sighted in the vicinity of Muskeg River. Maximum number observed at one time was about 100 Canada geese. In addition, 60 snow geese *(Chen hyperborea)* were observed on one occasion in the west end of the lake. Geese were present in the Kakisa area from the end of August to late September.

The eastern end of Kakisa Lake was heavily used by whistling swans throughout most of September. Swans were frequently observed along the eastern shore of the lake from Muskeg River to Kakisa River. Maximum number observed in one sighting was approximately 200.

Rare Predatory Birds

The Kakisa Lake area had a highly visible population of bald eagles *(Haliaeetus leucocephalus)* and ospreys *(Pandion haliaetus)*. Sightings of both species were almost inevitable on any outing lasting more than a couple of hours. They appeared to frequent the ends of the lake more than the long shores.

Only one active nest of bald eagles was positively located, at the site of the old Indian village (Fig 1). Judging from frequency and spacing of sightings, we estimate that the number of eagle nests around the lake was probably five, and the probable number of osprey nests was three or four.

Furbearers and Small Game

Beavers *(Castor canadensis)*

Of the major furbearers beavers were most heavily dependent on vegetation closely bordering Kakisa Lake. Each of the minor inlet streams had a lodge near the lake. Each stream also had a second lodge at a variable distance (usually less than 1 mi (1.6 km)) upstream from the first lodge. Six active lodges were located below the 732 ft contour to the west of the lake and four to the east. Estimated annual production of these 10 lodges would be 20 - 30, based on the assumption that one breeding pair per lodge would be able to raise 2 - 3 offspring through the first two winters.

Several lodges were not counted, because they did not appear to be in use, but there were several areas of heavy beaver sign where no lodges could be found, suggesting that bank burrows were being used. Thus our estimate of beaver population within the zone of flooding is likely conservative. Total population could conceivably be as high as 20 to 25 adult pairs.

Snowshoe Hares *(Lepus americanus)*

There was very heavy sign of snowshoe hares in the low areas around the east end of the lake. Kakisa villagers snared many hares in the area for food and trap bait. There are no recent records of their fur being sold.

It is likely that the low willow vegetation west of the lake was also heavily used by hares in winter.

Hares reach high numbers about once each decade and the winter of 1971-72 appears to have been such a peak year (Fuller, pers. comm.).

Lynx *(Lynx lynx)*

The principal areas for trapping lynx were along cutlines and east end rivers, well above the zone of flooding.

Trapping success in low-lying areas near the lake was reported to be low by native trappers. Since hares are practically the sole diet of lynx in winter, it appears contradictory that lynx should appear scarce in good hare habitat. It is quite possible that factors such as trap-shyness, poor visibility of bait and presence of hares springing lynx traps adversely affected trapping success in low areas near the lake. It appears certain that lynx must benefit from the hare habitat near the lake, either by direct hunting or at least by the hunting of surplus animals that wander out of optimum habitat.

Red Squirrels *(Tamiasciurus hudsonicus)*

The best habitat for red squirrels is in mature white spruce areas. Such areas are rather limited in extent within the area to be affected by flooding. The major stand of white spruce lies in a narrow strip 200 to 500 feet wide and 20 miles long along the north shore of Kakisa Lake. This area could support approximately 620 squirrels at an assumed density of 0.62 squirrels per acre, the maximum spring density at Heart Lake, N.W.T. in 1968-69 (Zirul and Fuller, 1971). Other areas lie in the upper reaches of Muskeg and Little Rivers and along the banks of Tathlina and Kakisa Rivers. Of the latter sites, only the five mile stretch of white spruce forest along the Kakisa River would be affected by flooding.

Marten and Mink *(Martes americana* and *Mustela vison)*

We obtained no precise data on the distribution of martens and mink. There may be a concentration of martens close to the lake and its streams because of the likelihood of high concentration of small mammals (mice and squirrels) in the productive habitats there. Burt and Grossheinder (1952) reported that stream and lake banks are the usual denning habitats for mink. In addition their diet of small mammals, birds, eggs and fish would favor their concentration in the vicinity of the slow inflowing streams of Kakisa Lake.

Muskrats *(Ondatra zibethicus)*

There were small areas of emergent vegetation suitable for muskrats along Little River and along Rivers 1, 2 and 3. Populations in these areas were not exceptionally high, as evidenced by the infrequency of sighting of animals. Extent of this river habitat is approximately 8.6 linear miles. Errington (1962, p 336-37) calculated spring populations of 65 adults and fall populations of 245 adults and juveniles for a nine mile stretch of Squaw Creek in central Iowa. It is likely that Squaw Creek adult populations and rate of production of young would be considerably higher than those of Kakisa Lake, where climate is severe and edaphic conditions are less favorable.

Spruce Grouse *(Canachites canadensis)*

The spruce grouse was the only upland game bird observed in the vicinity of Kakisa Lake. Some grouse activity was noted in mixed white spruce areas near the mouth of Muskeg River. Spruce grouse were also sighted on the south shore of the lake on the steep slopes. It appears likely that the north shore, with its dense white spruce growth near shore, would also be spruce grouse habitat, but no sightings were made to confirm this.

Big Game

Moose *(Alces alces)*

Summer moose forage of aquatic vegetation is available in fairly large quantities in the eastern and western ends of the lake, and in the slow inflowing streams. Winter browse of willow and aspen is abundantly available to the east and west of the lake up to an elevation of approximately 734 ft (223.7 m).

The land east of the lake was extensively travelled in the early spring (March - April) and little or no sign of browsing activity could be found, indicating that the moose population was low for the quality of the habitat. It appears that hunting pressure in areas around the lake have reduced moose populations to low levels. The Peace-Athabasca Delta Project (1973, pp 74-76) reported that average moose density on the delta in 1971 was 0.93 moose/mi^2 (0.24 moose/km^2) and maximum density was 5.1 moose/mi^2 (1.97 moose/km^2). The low moose density was attributed to heavy hunting pressure. They estimated that actual average carrying capacity was approximately 6.5 moose/mi^2 (2.51 moose/km^2).

At Kakisa Lake, about 13 sq mi (33.7 km^2) of low-lying habitat below elevation 734 ft (223.7 m) could be classified as good moose habitat. In addition 1 - 2 mi^2 of low-lying Kakisa River delta area could probably be classified as excellent habitat. If it is assumed that hunting pressure and habitat conditions in the optimum areas around Kakisa Lake are roughly equivalent to average conditions on the Peace-Athabasca delta, the present moose population for approximately 15 mi^2 (39 km^2) of good Kakisa habitat could be estimated to have an actual moose population of 14 and a potential population of 98 moose.

Bears and Wolves *(Ursus americanus* and *Canis lupus)*

Bear tracks were commonly sighted on lake beaches and along banks of streams. Two sightings were made by our field party, one on the south shore of the lake and one on the south bank of the Muskeg River.

One female bear and her cubs were shot by a villager in the Muskeg River area. A bear frequently visited the camping site at Lady Evelyn Falls.

Commercial fishing on Kakisa Lake doubtless attracts bears to the area since thousands of pounds of pike and suckers are discarded in addition to several thousand pounds of walleye entrails.

Wolf tracks were commonly seen on the north shore sand beaches but no animals were sighted.

Trapping Records

Trapping records for the years 1969 to 1972 are presented in Table 28. It should be noted that the 1972 figures are incomplete and do not include beavers shot in the spring which normally add significantly to the total. It can be seen that trapping effort has been quite consistent from year to year. On a three year total, lynx was the major economic species, followed by beaver and mink. Marten was a distant fourth. All other species combined accounted for about $400.00, less than 5% of the total.

The relative importance of the three major furbearers varied from year to year. The importance of lynx is probably related to the present high price of spotted cat fur and possibly to a cyclical high in the lynx population. On a long-term basis, beaver probably produces a larger income than lynx.

Of the approximately $3,000 worth of furs that were traded each year, it is unlikely that more than 20% of the furs came from the immediate Kakisa Lake area.

Most traplines extended many miles from the lake. In addition, significant amounts of furs were taken from the Tathlina Lake area. However, considerable effort was expended by nearby traplines. Moreover, these nearby traplines tended to be maintained by older villagers who were unable to cover the long distances required to maintain the distant and more lucrative traplines.

Human Ecology

The lifestyle of the Kakisa villagers is intimately tied to the biological resources of a large geographical area extending over more than two-thirds of the Kakisa River watershed. This area includes Tathlina Lake and its inlet streams, Kakisa Lake and its inlet streams and Kakisa River down to Beaver Lake.

Fishing on both Kakisa and Tathlina Lakes is the mainstay of the village economy and the chief source of cash income. Trapping is an important supplementary form of income. Land use patterns tend to follow a pattern which is repeated annually with a limited amount of variation.

In mid-winter, a limited ice fishery at the mouth of Tathlina River on Kakisa Lake sustains dogs in the village and provides a small cash income. At that time there is also a limited ice fishery on Tathlina Lake in the main inlet river region, as well as considerable trapping and hunting along the streams running into Tathlina Lake. There is trapping activity in the Kakisa Lake area, principally along Tathlina, Kakisa, Muskeg and Little Rivers, and along various cutlines. Most trapping activity radiates from the eastern half of the lake. Dogsleds are the only means of transportation used by natives in the winter. Some 70 dogs are maintained in the village year round for winter transportation. They necessitate a fairly constant level of fishing and drying of fish on the part of the villagers. The white villagers, all members of one family, are fully mechanized, and maintain no sled dogs.

Just before breakup there are strong movements of walleye into spawning areas. At that time, native villagers move their Kakisa Lake fishing operations from the mouth of Tathlina River to the mouth of

Muskeg River. Simultaneously there is intensified ice fishing effort at the main inlet to Tathlina Lake by both white and native fishermen. Spring ice fishing in Tathlina Lake is lucrative but of short duration. When planes can no longer land on the ice, or the ice is unsafe for large snowmobiles, the entire operation is abandoned, and all fishing effort reverts to Kakisa Lake.

Muskeg River is fished until it is possible to traverse the lake by boat to Tathlina River at which time most villagers, native and white, become involved in intensive fishing in the vicinity of the Tathlina river-mouth area and continue until the limit of 41,000 pounds of walleye is reached.

Once spring fishing is over, there is traditionally a spring hunt up Tathlina River to Tathlina Lake. During the trip upstream, beavers are shot. On Tathlina Lake geese and ducks are shot and moose is hunted for a summer meat supply. Additional beavers are shot on the inlet streams of Tathlina Lake. The hunt generally lasts for 6 weeks. This year was the first year that the spring hunt was not undertaken for reasons not yet clear.

After the spring fishing (and normally the spring hunt), hunting and fishing activity is greatly reduced until about mid-September. Throughout summer, sporadic hunting takes place and only sufficient fish are caught to maintain the dogs.

In fall, hunting activity increases. Geese and moose are sought in the west end of the lake. In mid-September, some men move down to the mouth of Kakisa River near Beaver Lake, catch up to 20,000 pounds of spawning whitefish for winter dog food and shoot large numbers of ducks and geese for themselves.

The whitefish are dried in permanent buildings located about 2 miles upstream from Beaver Lake. The fish are stored in these smokehouses, and the villagers make periodic trips by dogsled during winter to replenish their dog food supply.

In late fall some villagers return to Tathlina Lake to fish through the ice for walleye near the inlet stream. Some overwinter at Tathlina to trap, fish and hunt. The quota for walleye on Tathlina Lake is 70,000 pounds. The proportion of the quota removed during fall varies from year to year. Some years it is the major proportion, other years it may be a very small proportion. A large proportion of the Tathlina quota is taken by white fishermen.

Kakisa villagers engage in a limited amount of outside work during the quiet summer period. One man has a full-time outside occupation while the remainder work sporadically as casual laborers, firefighters, commercial fishermen on Great Slave, brush cutters, chainmen or heavy equipment operators.

The way of life of Kakisa villagers is largely centered on traditional occupations of fishing, hunting and trapping, which appear to supply adequately the basic necessities. Some adaptations of this way of life to a cash economy have been made.

No shortage of food or serious health problems were observed. The only major input of federal social assistance has been provision of building materials and technical assistance in constructing the cabins occupying the present site. On a continuing basis, there have been no major inputs of welfare money other than normal social security programs available to all Canadian citizens. Collection of welfare money by able-bodied men has been, at most, a rare occurrence.

The impact of Kakisa Village on the natural environment, exploited by the native people, has been minimal. The only noticeable effect is a localized scarcity of moose near Kakisa Lake. The minimal damage to the natural environment and the comparatively high standard at which the people of Kakisa have been able to support themselves is no doubt due to the large area of natural environment utilized and to the rotational manner of this utilization. Moreover, the population of the village has been stable for several decades. Native population of the village now stands at 43. This has no doubt been an instrumental factor in the overall economic success of the community.

A fact sheet (Table 29) of social and economic information related to land use by the residents of the Kakisa area has been included. It should be emphasized that the values listed for presently used fishing, hunting and trapping resources are gross values. No attempt has been made to estimate the considerable expenses involved in procuring and shipping these biological resources. In many cases these expenses may exceed half the value of the resource.

It should be noted that large quantities of fish and game are derived from the immediate environment for food. Its value, when calculated on the basis of the value of equivalent purchased supplies, is considerable.

Another point that should be noted is that native people gain considerably greater economic livelihood from the Kakisa Lake environment than from the Tathlina Lake environment. White villagers, on the other hand, derive the major portion of their livelihoods from Tathlina Lake.

PROBABLE ENVIRONMENTAL EFFECTS OF HYDRO DEVELOPMENT

General

It should be understood from the outset that almost any hydro development causes some net reduction in existing biological assets (c.f. Cuerrier, 1954; Rawson, 1958; Stube, 1958; Miller and Paetz, 1959; Grimas, 1961, 1962, 1964, 1965; Neel, 1963; Runnstrom, 1964; Nilsson, 1964; Nelson 1965). Therefore any environmental assessment tends to read negatively. The reader should not construe this as a value judgement on the writer's part as to the overall merits of the development. The value judgement that must be made is not whether a proposed project would be environmentally beneficial, but whether changes in the natural environment would not be so great as to negate the positive economic benefits of the project.

Basis of Assessment

The assessment of environmental effects is based on a graph (Fig 14), supplied by Underwood, McLellan and Associates, which shows Kakisa Lake water levels from 1962 to 1972. Three separate water level regimes, designated as lines A, B, and C, have been drawn on Fig 14. Line A indicates estimated naturally occurring water levels for the period of record. Lines B and C indicate water level regimes that would have occurred if the lake had been developed for 6 and 8 ft (1.83 and 2.44 m) of live storage, respectively, during the period of record. For purposes of brevity of description, the option of "no development" will be designated as Scheme A, the option of development of 6 ft of storage" as Scheme B and the option of "development of 8 ft of storage" as Scheme C. The remainder of this thesis will deal with the physical and biological differences among the three options. Predictions of possible effects of development will be based on the writer's assessment of what would have happened with Schemes B and C over the period of record.

The lines B and C on Fig 14 are based on the assumption that a firm flow of 1500 cfs would be passed downriver from May 1 to September 1, and that a firm flow of 1250 cfs would be passed during the other 8 months of the year. Reservoir water levels have been established by using a rating curve of outflow vs. lake level in conjunction with flow records from the Water Survey of Canada metering station on Kakisa River. The rating curve, upon which estimates of lake levels are based, was established for a narrow range of water levels and flows during the summer of 1972, and could be substantially in error for high flows (C. Anderson, UMA, Personal Communication). Moreover, the rating curve probably varies from year to year in response to annual differences in the pattern of weed growth in the outlet area.

The writer has no alternative but to assume that all information supplied by other sources is correct, and that reservoir operation will be carried out exactly as described. Any changes in operation or errors in information supplied could significantly alter predictions of likely environmental effects. Therefore, any such changes would require re-evaluation of the environmental effects of development.

In the discussion that follows and in the accompanying figures and tables, use will be made of the concepts of both mean and median values to describe water levels and water level differences. The mean is simply the arithmetic average of all observations for the period of record. The median value is here defined as the fourth highest value of the 8 year period of complete records (i.e. 4 out of 8 values are less than or equal to the median). Since means and medians convey slightly different meanings, especially when the data are strongly biased in either the high or low direction, both statistics are used for the sake of completeness.

Differences among Water Level Regimes for Schemes A, B and C

Fig 15 shows frequencies of occurrence of water levels for each scheme for each month of the period of record. It can be seen that regulation results in an upward shift in a range of water levels rather than a discrete change in water levels. The overlap of frequencies of occurrence of water levels is quite strong between Scheme A and Scheme B. It is also quite strong between Scheme B and Scheme C. However, there is very little overlap between Scheme A and Scheme C.

Table 30 shows that there are only very small differences in annual water level fluctuation among Schemes A, B and C. Average annual fluctuations are 4.2, 4.1 and 4.3 ft (1.28, 1.25 and 1.31 m) and maximum annual fluctuations are 5.5, 5.3 and 6.2 ft (1.68, 1.62 and 1.89 m) for Schemes A, B and C, respectively.

However, timing of water level fluctuation is substantially different in unregulated and regulated schemes. In regulated schemes, the rate of water level drop in summer is reduced, whereas the amount of water drop in fall and winter is increased. These relationships are shown in Tables 31 and 32.

Average drawdowns (Table 31) of 2.3, 3.3 and 3.3 ft (0.71, 1.01 and 1.01 m) occur for Schemes A, B and C, respectively, for the period between August 1 (time of maximum extent of rooted aquatic vegetation) and the spring low. Although the differences in average drawdown among the three schemes are quite small, differences in maximum drawdown for the period of record can be somewhat larger. Maximum drawdowns are 3.1, 4.8 and 5.2 ft (0.96, 1.46 and 1.59 m) for Schemes A, B and C, respectively.

Average drawdowns (Table 32) of 1.8, 3.1 and 3.2 ft (0.56, 0.96 and 0.98 m) occur for Schemes A, B and C, respectively, for the period between October 1 (time of fall spawning) and the spring low. Maximum drawdowns are 2.6, 4.2 and 4.1 ft (0.79, 1.28 and 1.25 m) for Schemes A, B and C, respectively.

The amount of fluctuation of water level that occurs and the timing of fluctuation profoundly affect biological processes in the lake. Of particular importance are the effects of water level fluctuations on aquatic and terrestrial vegetation and upon fish and wildlife which will be discussed in later sections.

Actual water levels that occur are at least as important biologically as the amount of fluctuation in these levels. Duration for which water levels occur and the timing of their occurrences are the most critical aspects of water levels. Mid and later summer water levels are especially important for both aquatic and terrestrial vegetation. Spring minima and maxima are important fisheries and wildlife considerations.

Fig 16 and Table 33 show the differences in water levels among the three schemes of development. In June Scheme B and C have water levels which average 0.6 and 2.1 ft (0.18 and 0.64 m) higher, respectively, than the average for Scheme A. In July the figures are 1.7 and 3.2 ft (0.52 and 0.98 m) in August 2.1 and 3.5 ft (0.64 and 1.07 m) and in September 2.0 and 3.5 ft (0.61 and 1.07 m). Thus, it can be seen that the differences between regulated and unregulated schemes become larger as the growing season progresses, while differences between the two regulated schemes remain approximately constant throughout the growing season.

Table 34 shows the differences in water levels among Schemes A, B and C in a year (1965) when differences among the schemes were quite pronounced. Differences between regulated and unregulated cases are substantially higher than for the average year, and the difference between Schemes B and C is a constant 2 ft (0.61 m) throughout the summer, a value which approximates the maximum possible difference between these two schemes.

Land to be Flooded

Contour maps supplied by Underwood, McLellan and Associates indicate extensive flooding of riverbank and shoreline vegetation in the western end of the lake when lake water level reaches 728 ft (221.89 m) Fig 14, also supplied by Underwood, McLelland and Associates, shows the peak 1972 water level to be 728 ft. Therefore, according to this graph there should have been noticeable flooding in the west end at the time of maximum levels. But the area was examined by field parties on June 21 when lake level was at or near its 1972 peak, according to the recording flow meter on Kakisa River, and the west end streams were found to be bank-full but not flooding. This discrepancy was brought to the attention of the above engineering firm, and the contour maps of the west end were checked for accuracy. This check indicated that there were no significant mapping errors, so it can only be concluded that the water level vs. outflow graph (Fig 14) for Kakisá is significantly in error, and that it gives values that overestimate maximum historical lake levels by at least a foot. In veiw of this, it would appear that the historical maximum lake level of 729.4 ft (222.32 m) is somewhat in error and may give an overly optimistic picture of the ability of the low-lying terrestrial vegetation to endure flooding.

In any event, there is no evidence of damage to terrestrial willow and aspen vegetation due to the high water levels of 1962. Hay River records indicate that 1962 was the lowest of four consecutive years (1960-63) of high rainfall (C. Anderson, U.M.A. Personal Communication). Therefore, it is likely that similar high early summer water levels occurred in the other three years, although no record exists. It should be noted, however, that high water levels occur for a longer period of the growing season under Schemes B and C than under Scheme A. Under natural conditions, high water levels are almost always followed by a strong receding trend which allows the root system of flooded trees to recover from the adverse effects of spring flooding.

Table 35 gives a breakdown of the area and location of lands that would be affected by raised water levels under Scheme C. Lands below elevation 732 ft (223.11 m) would be subjected to the direct effects of flooding and wave action. These lands amount to 8.78 mi^2 (22.74 km^2). Lands between 732 and 734 ft (223.11 and 223.72 m) would be subject to varying amounts of wave action and to the effects of raised water table. Total area of land in this contour interval is 4.21 mi^2 (10.90 km^2).

It should be noted that the greatest area of land affected by raised water levels would be to the west of the lake. The east shore would be the second most affected area. The north shore would undergo a much smaller amount of flooding in terms of area, but in terms of linear miles flooding effects would be substantial. The low-lying rivermouth of Tathlina River would be heavily flooded. The long south shore of the lake would undergo negligible flooding because of its steeply sloping shores.

The amount of direct flooding with Scheme B would be proportionately less than for Scheme C. Actual flooding of terrestrial habitat would not start to occur until some elevation between 726 and 728 ft (221.28 and 221.89 m) was reached. The zone subjected to water table and wave-action effects would be at least as large for Scheme B as for Scheme C, since the area between the 729 and 731 ft (222.19 and 222.89 m) contours is at least as large as that between the 731 and 733 ft (222.80 and 223.42 m) contours. Exact figures are not available, since the mapping is in 2 ft (0.61 m) intervals.

Topography and Geomorphology

Shoreline Erosion

Along the exposed northern shore, it is reasonable to expect that the effects of wave erosion should extend to at least 2 ft (0.61 m) above full supply level.

Since major soil development starts at the tree line at approximately elevation 729.5 ft (222.35 m), it follows that Scheme B, with a full supply level of 729.2 ft (222.26 m) would have a minimum zone of erosion of 1.7 ft (0.52 m), between elevations 729.5 and 731.2 ft (222.35

and 222.86 m) whereas Scheme C, with a full supply level of 731.2 ft (222.86), would have a minimum zone of erosion of 3.7 ft (1.13 m) between elevations 729.5 and 733.2 ft (222.35 and 223.48 m).

The south shore, with its steep, boulder shores and almost total lack of soil development below elevation 733.2 ft, should experience only negligible erosion.

The west shore of the lake might be quite well-protected from wave erosion, in view of the fact that it is sheltered by sandbars. Moreover, the wide flat expanse of the areas to be flooded might effectively dissipate wave action, by producing considerable bottom drag on incoming waves. In addition, aquatic and emergent vegetation might provide a further dampening effect on waves approaching shore. Ice erosion might prove a more significant erosive force than wave-action in the west end of the lake. Areas which, under natural conditions, are never flooded at the time of freeze-up, would generally be covered with a thick ice sheet in winter under Schemes B and C. As the water level was lowered during the winter, this ice sheet would come in contact with the entire area of the flooded land. Soil could adhere to the lower surface of the ice sheet and could be removed and transported into the lake system when the ice floated up in the spring. Thermokarst subsidence would occur in the west end of the lake if the patterned ground observable in the area to be flooded represents active permafrost and is not just a manifestation of an earlier permafrost occurrence. Finally, there is a possibility that floating peat islands, from areas of floating sedge bogs and muskegs, could break loose as the result of the bouyant effect of raised water levels.

It would appear that erosional effects in the west end would be more severe under Scheme C than under Scheme B. With the higher water levels of Scheme C, sandbars, aquatic weedbeds, emergent weedbeds and bottom-drag would provide less protection from wave action to flooded lands near the present shoreline than they would with Scheme B. In addition Scheme C would expose a much greater area of land than Scheme B to the special erosional effects previously mentioned.

The eastern shore of the lake would seem to present an erosional situation intermediate between that occurring along the north shore and that occurring in the west end. Effects of wave-action should be less than they would be along the north shore because of the dissipating effects of a flatter-sloping shore. However wave-action should be considerably more severe than in the protected west end. The effects of ice-erosion should be more severe than in the west end because of greater exposure to wave-action during breakup. There should be only limited possibilities for thermokarst activity and the breaking loose of peat floating islands, since areas susceptible to these types of processes are uncommon on the eastern shore of the lake.

In all parts of the lake, the effect of ice erosion may be somewhat reduced if significant melting of shore ice occurs prior to a major rise in lake level. However, erosive effects of ice push, caused by thermal expansion of ice prior to major thawing, should occur in all years.

Morphological Changes in Lake Basin

Raised water levels would radically alter the relative contributions of the various depth zones to the total lake area. Reasons for this are two-fold. The lake bottom near the eastern shore of the lake is fairly steeply-sloping above elevation 722 ft (220.06 m) and is very gently-sloping below that elevation. As a result, regions immediately below elevation 722 represent a major portion of the total lake area. The situation is illustrated graphically in Fig 17 and 18 in five typical profiles of the eastern shore of the lake (Sections AA to EE). In the west end of the lake virtually the entire lake bottom of the shallow water area is at an elevation of approximately 720 ft (219.45 m). The transition zone near shore is quite narrow and is insignificant in terms of percentage of the entire lake area. The situation in the west end of the lake is depicted graphically in Fig 18 in three typical profiles (Sections FF to HH).

Along the north and south shores of the lake the transition from shore to a depth of 4 m (13.10 ft) is fairly abrupt. The contribution of these areas to the shallow zones of the lake is small compared with that made by the eastern and western ends of the lake.

Changes in lake morphology resulting from Schemes B and C for the August 1 median water level are shown in Table 36. For Scheme B there is a significant decrease in the area of the 1 - 2 m (3.28 - 6.55 ft) zone, mostly because the entire western part of the lake becomes included in the deeper 2 - 3 m (6.55 - 9.75 ft) zone. Part of the decrease is also accountable to an upward shift on the more steeply-sloping part of the eastern shore. This upward shift in water levels also causes a decrease in the 3 - 4 m (9.75 - 13.10 ft) zone as the result of a large part of this zone becoming part of the 4 - 5 m (13.10 - 16.40 ft) zone. For Scheme C there is a further decrease in the 1 - 2 m zone, as the entire zone in the east end becomes confined to the steeply-sloping part of the shore. There is a further decrease in the 2 - 3 m and 3 - 4 m zones as a result of the upward shift of depth zones on the eastern shore. There is a significant increase in the 0 - 1 m (0 - 3.28 ft) zone as the result of the flooding of large areas of terrestrial habitat.

The morphological situation for the more extreme case of 1965 is depicted in Table 37. It can be seen that Scheme B in that year would have resulted in a situation similar to Scheme C in the median year. It is also noteworthy that the change of water level from 729.2 to 731.2 ft (222.26 to 222.86 m) from Scheme B to Scheme C in 1965 would cause considerably less additional morphological change than does the change from 728.0 to 729.9 ft (221.89 to 222.47 m) from Scheme B to Scheme C in the median year.

Morphological Changes in Streams

The normal variations in depth of streams just adjacent to the lake are shown in Fig 19. In the minor inflowing streams, the gradient near the lake is so low that lake levels influence river depths for distances which usually exceed a mile. Thus, lake level has a strong effect on river processes in these reaches.

Schemes involving raised water levels would obviously have the effect of deepening reaches of streams within the zones influenced by raised water levels. Figs 20 and 21 give minimum, median and maximum depths for all streams (near the lake) for June 15 and August 15, respectively, for the period of record. It can be seen that the deepening effect is less marked on June 15, when natural levels are high, than on August 15 when natural levels are normally much lower than regulated levels.

The deepening of streams should bring about decreases in velocity in the reaches adjacent to the lake. If it is assumed that the river channels are roughly rectangular and that the flow would be contained within existing river banks, the velocity after regulation would be roughly equal to

$$\frac{\text{depth without regulation}}{\text{depth with regulation}} \times \text{velocity without regulation}$$

The implication of lowered velocity is that finer particles than are presently deposited, would settle out on stream beds within the zone of influence of raised water levels.

There is no quantitative data on silt loads and stream flows presently available that would allow reasonably accurate predictions of the siltation processes to be expected. However, qualitatively, it appears that only Tathlina River, Muskeg River and possibly Little River carry appreciable quantities of suspended particles. Nothing is known of their bed loads.

With higher water levels deltaic deposition should occur further upstream in the rivermouth of Tathlina and Muskeg Rivers.

Summer deposition of fine materials in Tathlina and Muskeg Rivers proper should also increase. It would still appear likely that much of the finest material would be scoured during high spring flows, even with slightly raised water levels. Nevertheless, some consideration of siltation phenomena should be made, especially for Muskeg River, a major spawning stream, where gravel suitability appears to be only marginally adequate and where most spawning areas fall within the sphere of influence of lake levels.

Kakisa River would undergo the most significant changes of any of the streams affected by raised water levels. Water depth just above the dam would be increased to 50 or 60 ft (15 or 18 m) compared to the present mean depth of approximately 4 ft (1.2 m). Such an increase in depth would result in velocities above the dam being roughly one fifteenth of naturally-occurring velocities. Lowered velocities above the dam should result in relatively heavy siltation upstream of the dam and a greatly clarified river flow downstream of the dam. This clarified flow would theoretically have a high potential for accelerating downstream erosion. However, peak flow rates under regulation would be much lower than natural peaks. Therefore this erosive potential should not be realized under normal plant operation.

Vegetation

Aquatic Vegetation in Kakisa Lake

Morphology of the littoral zone, overwinter water level fluctuations, substrate type and wave exposure are postulated as the chief factors governing the distribution of aquatic vegetation in Kakisa Lake.

Even under natural conditions, lake ice and drop of water level over winter may significantly influence the pattern of growth of aquatic vegetation.

Quennerstedt (1958) has shown that the upper limit of aquatic vegetation in natural and regulated Swedish lakes corresponds very closely with the lowest winter water level. In lakes with large overwinter drops in lake level, the zone is reduced or eliminated.

In Kakisa Lake, the average drawdown for the years of record from the peak of aquatic vegetation around August 1 to the spring low is about 2.3 ft (0.70 m). In addition approximately 3 ft (0.92 m) of ice forms on the lake in winter. Thus an average of 5.3 ft (1.62 m) of littoral zone is normally subjected to severe conditions of cold and desiccation.

McAtee (1939) attested to the ability of seeds of *Potamogeton* to endure freezing and desiccation. Sculthorpe (1967, p 346) stated that winter buds and tubers, while dormant, show a certain resistance to adverse conditions, which is endowed by their mucilaginous covering or protective scale-like leaves, but since they lack any hard, thick impermeable coat, this resistance is undoubtedly limited. It is, therefore, likely that only seeds would be able to survive in the zone above the lowest annual elevation of the bottom of the ice sheet. Since winter buds and tubers are a much more efficient means of propagation than seeds, it is hypothesized that the major zone of propagation of *Potamogeton* species is below the minimum spring elevation of the bottom surface of the ice sheet. Growth of aquatics in shallow areas is probably more the result of growth from perenniating stock than of growth of new plants from seed.

The average increase in water level drop from August 1 (the time of maximum extent of aquatic vegetation) to the spring minimum is only one foot greater for the Schemes B and C than for Scheme A. An extra foot of drop would decrease the perenniating stock of rooted aquatics but would by no means eliminate it. A reduction in the area of perenniating stock could have the effect of slowing down the vegetative spread of rooted aquatics into the shallow zones in the summer.

In certain years, such as 1966-67, 1967-68 and 1970-71, Schemes B and C have particularly large water level drops over winter of the order of 5 ft (1.53 m). They are significantly larger than the maximum water level drops of about 3 ft (0.92 m) under natural conditions. A water level drop of 5 ft and a 3 ft ice cover would mean that the refuge for overwintering plants would be reduced to a zone below 8 ft (2.44 m) in depth. Since the lower limit of plant growth is only about 10 ft (3.05 m) the area of refuge would be quite small. If a large drop in lake level were to occur in a dry year, such as happened in 1969-70, and there was high runoff the following spring, it is conceivable that the overwintering stock of winter buds and tubers could end up covered with 10 to 12 ft (3.05 to 3.66 m) of water the following summer. This would be a rather unfavorable growth situation and could result in failure of most of the annual crop of aquatic vegetation. It could take several years for stock of perennial aquatic plants to recover from such a setback. If, on the other hand, the year following the large winter water level fluctuation, is normal or dry, the main effect might be only a less abundant crop than in years when over-winter fluctuation is smaller.

This analysis of the effect of over-winter fluctuations in water level on aquatic vegetation has been based on the assumption that the water level regime of Fig 14 would be strictly adhered to. If use were made to carry-over storage in the spring, the amount of over-winter fluctuation would be substantially increased, and the worst case discussed in this section would apply more frequently.

Changes in morphology of the littoral zone, resulting from raised water levels, could have a greater effect on rooted aquatic vegetation than over-winter water level fluctuations. When water levels are higher during the growing season for rooted aquatics, potential growth zones for aquatics are compressed onto the more steeply-sloping part of the shoreline.

The large reductions that would take place in the 1 - 2 m and 2 - 3 m zone in the east end of the lake have already been discussed in the section on lake morphology. Since virtually all growth of rooted aquatics takes place between 1 - 3 m, reductions of rooted aquatics in the east end of the lake should be considerable. Table 38 demonstrates the effect on rooted aquatics in the east end of the lake. It can be seen that Scheme B involves a 16% increase in the 1 - 2 m zone in the median year and a 38% decrease in the 2 - 3 m zone. Scheme C involves a 62% decrease in the 1 - 2 m zone and a 50% decrease in the 2 - 3 m zone. In a year such as 1965, Scheme B would have percent decreases similar to Scheme C in the median year. For Scheme C in 1965, percent reduction in the depth zones suitable for aquatic vegetation would be slightly greater than in the median year.

With a greater depth of water over the shallow, flat zone (presently 3 - 4 m) of the east end of the lake, bottom drag should be less effective in dissipating wave-action. In addition the narrowing of the zone suitable for rooted aquatic vegetation should increase wave-exposure for the remaining beds of rooted aquatics. The resultant overall increase in wave-action could bring about a further reduction in area and stem density of beds of aquatics. However, the effect is hard to quantify.

In the west end of the lake, the rise in water level of Schemes B and C should not be sufficient to totally prevent growth of rooted aquatics by reduction in light penetration to the bottom. However, conditions of light on the bottom of the bay in the west end should be just marginal for growth, especially with Scheme C. Therefore, it is reasonable to predict a decrease in stem density.

The newly-flooded areas of the east and west ends of the lake should have some potential for supporting new growths of aquatic vegetation. However, it should be remembered that these areas would normally be subjected to winter drawdown which could impair their ability to sustain dense growths of rooted aquatics.

Rooted Aquatics in Rivers

The extent of rooted aquatics in rivers is largely determined by the degree of penetration of light to the bottom and by substrate suitability. It can be seen from Table 8 that turbidity in the slow-flowing rivers approximates that occurring in the lake proper. Color in the slow-flowing rivers is appreciably higher. One would therefore expect maximum depths for aquatic plants in the rivers to be no greater than those in the lake. This would imply a maximum depth range between 3 and 4 m (9.75 to 13.10 ft). It can be seen from Fig 21 that Scheme B should likely have an effect only on River 2, whereas Scheme C could have an effect on Little River and River 2 during the median year. For the most extreme case, when maximum summer water levels of 729.2 and 731.2 would occur for Scheme B and C, respectively, Little River and

River 2 still appear to be the only streams that could be significantly affected.

Emergent and Wetland Vegetation

Tables 36 and 37 show that Scheme B brings about an increase in the 0 and 1 m zone only during years when full storage capacity is realized (e.g. 1965). Scheme C brings about an approximate doubling in area of the 0 - 1 m zone. Much of the increase is the result of flooding of low-relief terrain in the eastern and particularly in the western end of the lake. As a result, it is reasonable to expect a significant expansion of areas of emergent vegetation in those areas.

Existing sedge meadows which are largely above normal water level during the growing season would undergo flooding under both Schemes B and C. This should cause vegetational shifts and should result in encroachment of *Equisetum* (horsetails) and *Scirpus* (rushes) onto the sedge meadows. This shift should be much less pronounced for Scheme B than for Scheme C.

There is some possibility that ice erosion in the newly flooded areas could cause considerable vegetation and soil disturbance in newly-flooded areas and could prevent the full potential of these areas for emergent vegetation from being realized.

Terrestrial Vegetation

It goes without saying that all tree species consistently flooded throughout the growing season would be certain to suffer mortality. The effects of intermittent flooding and raised water table are somewhat more complex questions. Quennerstedt (1958) stated that, in north

Swedish water systems such ad the Sketlefte River basin system, the littoral *Salix* bushes *(S. lapponum* and *S. glauca)* were killed when water level was held at the pre-existing natural high water mark for a longer period than is normal during the vegetation period. Thus, any scheme of flow regulation for Kakisa that has the potential to keep water levels at or above normal high water levels for a major part of the growing season would almost certainly cause 100% mortality of existing lakeshore and riverbank willow vegetation.

Mature aspen was generally found above elevation 729 ft (222.19 m) on the north shore of the lake and above elevation 728 ft (221.89 m) in the west end of the lake on well-drained, mineral soils in areas that were not normally flooded, even during high water. Immature aspen was found at elevations as low as 727 ft (221.58 m) but the absence of mature trees indicated that adverse environmental influences such as ice-action, wave-action and periodically high water levels eliminate them from these areas. Scheme B should flood some of the lower lying aspen and saturate soils in large areas where aspen is growing. In addition, aspen on the north shore that is not flooded would be subjected to wave-action. The above influences should cause significant mortality. With Scheme C this mortality would be more widespread and would encompass virtually all aspen vegetation on the north, east and west shores of the lake, on the banks of Rivers 1, 2 and 3, on the banks of Little River and around the mouths of Muskeg River and Tathlina River. Moreover, it could affect a significant part of the aspen vegetation of Muskeg River.

White spruce appears to have more stringent requirements than aspen and was seldom found below elevation 730 ft (222.50 m), well above probable maximum spring flood level. The major area of white spruce that would be affected by raised water levels occurs in a narrow, twenty-mile strip along the north shore. Scheme B would likely cause significant but not total mortality to white spruce in that strip. Scheme C might cause almost total mortality. The white spruce strip is backed by stunted black spruce muskeg vegetation.

Physical and Chemical

Spring Breakup

Obstruction of the Kakisa River with an impounding structure would prevent the normal free downstream movement of river and lake ice. Consequently, virtually all ice upstream of the dam (including the ice on Kakisa Lake) would be forced to melt in situ. With more ice on the lake during spring thaw, heating of the lake water would be less efficient, since ice absorbs much less energy than water. Moreover, total heat input required to melt the ice would increase, since latent heat of fusion required for melting would also have to be supplied to ice that normally would have passed downstream.

Field records for Kakisa River show that the river was ice-free on May 6, 1972. However, there is no record of the exact day ice went out of the river. Records of Water Survey of Canada (1972, raw data)* show virtually no change in gauge height from April 28 to May 8, 1972 at the Kakisa River gauging station. It can therefore be concluded that rise in river stage was not instrumental in the 1972 breakup, and that breakup was the result of gradual deterioration of the ice. It is difficult to extrapolate to other years to find a relationship between rising river levels and breakup, since records of exact breakup dates are not available. In some years, rising river levels may have accelerated breakup, but judging from the 1972 situation, breakup probably would not have been greatly delayed if river levels had not risen. It seems likely that the fluctuating output of the proposed power plant, coupled with the effect of the additional compensatory flow over the Falls which would start on May 1, should be adequate disturbance to hasten the breakup of deteriorating river ice.

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* Data sheets of daily discharge available from Water Survey of Canada, Fort Smith, N.W.T.

No major problems associated with downstream breakup are forseen. Moreover, if any delays were to occur, they could be easily eliminated by increasing rate of power generation to dislodge the ice.

Water Temperatures in Kakisa Lake

Since ice would not escape downstream during breakup, and since more energy would be expended in melting the larger quantity of ice, late spring and early summer water temperatures should be lower under regulation than under unregulated conditions. The time around the summer solstice is when the greatest amount of solar energy is available for organic production. Loss of much of this energy in late spring and early summer could significantly reduce annual production of the lake.

The rate of heating Kakisa Lake should also be somewhat reduced in spring and early summer by increases in the volume to surface ratios of Kakisa Lake, which could be as great as 25% for Scheme B and 40% for Scheme C. It should be remembered, however, that a large amount of the water contributing to increased lake volume is spring runoff which is already warmed to summer or near-summer temperatures. For example, on May 28, Muskeg River was 15.5°C (59.9°F) and on June 11, Tathlina River was 16.0°C (60.8°F). Thus, there was a net heat flow into the lake as a result of runoff.

The larger volume of water in the lake should also cause slight reductions in the amount of daily fluctuation of water temperatures and in the rate of cooling of the lake water mass in the fall. These phenomena should contribute slightly to a trend toward increased production. However, any production gains would be much less that the loss incurred by delayed spring warmup, principally because the solar energy available for organic production around the time of autumnal equinox is much less than the energy available around the time of summer solstice.

Water Temperatures in Kakisa River

Because of backup of ice behind the dam, water passing downstream of the Falls should be very cold until ice accumulation is melted. Thus, warmup of the stream, especially in the first few miles downstream of the Falls, should be appreciably retarded.

Delayed warmup of the stream could delay spring spawning and could result in some loss of annual production of bottom organisms.

Temperature fluctuations, after the ice is melted, could be larger than in the unregulated river, since summer flows of 1500 cfs are somewhat lower than the normal flows in June, July and August (Underwood, McLellan and Associates, 1972). However, they are quite similar to flows occurring in low flow years, and actually higher than average summer flows in years of extreme low flow, such as 1971 and 1972. Therefore, it appears unlikely that flow regulation would result in temperature extremes or fluctuations exceeding the limit of tolerance of the existing stream fauna.

It is not clear whether Kakisa River above the dam will stratify. Depth is in the range of stratified lakes and wind protection from the riverbanks is good. Therefore, the basic conditions for stratification exist. However, since water is still confined to a narrow river channel, turbulent currents might be sufficient to promote mixing. The question should be further investigated.

Stratification should have little effect on downstream temperatures, since the power plant draws water from near the surface of the reservoir where water temperatures are close to ambient temperatures. However, stratification often results in concentration of nutrients in the hypolimnion (below the level of the intake for the turbines) which could cause nutrient impoverishment downstream (Neel, 1963).

Fall Freeze-Up

Freeze-up can take place any time after water temperature reaches a uniform 4°C (39.2°F), provided sufficiently calm, freezing weather occurs. Since the lake becomes isothermal at 4° well before freeze-up (see p 15), it is unlikely that the slightly delayed cooling of Kakisa Lake, resulting from larger lake volume, would have any effect on freeze-up.

Dissolved Oxygen

Most of the water covering newly-flooded areas in late October would be less than 3 ft (0.9 m) deep and would likely freeze to the bottom. As the lake is drawn down during the winter, flooded areas that are not frozen to the bottom should become so. Since it seems almost certain that most newly-flooded areas would be frozen solid throughout most of the winter, and therefore isolated from the rest of the lake, it is unlikely that winter oxygen demand in flooded areas would have an appreciable effect on the lake proper. In general, the locations of anaerobic areas and aerobic areas should change little after impoundment and regulation. Anaerobic conditions should be confined to areas that have aquatic vegetation in summer and that have only a few centimeters of water between the bottom of the ice cover and the lake bottom in winter. Experience sampling through the ice in the spring of 1972 indicated that such areas occur only near the eastern and western shores, and that the boundary between anaerobic and aerobic areas of the lake is very sharp. Anaerobic areas did not seem to affect dissolved oxygen levels in the lake proper. There is no reason to believe that the winter dissolved oxygen situation should worsen after regulation, since potential anaerobic areas would be virtually identical. Moreover, the greater volume of water should actually increase the absolute amount of dissolved oxygen available over winter.

Decay of vegetation and organic soil may make appreciable summer oxygen demands. However, areas affected should be broad and shallow, and therefore susceptible to oxygenation by wind-action. Rooted aquatics and phytoplankton should also make a substantial contribution to oxygenation of the water during the long summer days. In the late summer and early fall, when the annual crop of aquatic vegetation and plankton is subject to rapid decomposition, the combined decomposition of this material and pre-existing organic material could cause localized lowering of oxygen levels in the flooded areas. It is unlikely, however, that the lowering of dissolved oxygen there would have a significant effect on dissolved oxygen in the lake proper, as these waters, in the most extreme possible case, contribute less than 1% to total lake volume.

pH

Active decomposition could slightly lower pH in the west end of the lake, but the small volume of water involved and the huge buffering capacity of the lake should ensure that any pH changes in the lake are insignificant.

Turbidity in Kakisa Lake

As discussed in the section on erosion, higher water levels should increase the absolute amount of silt-sized particles derived from shoreline erosion. However, this would not necessarily cause an increase in turbidity, because higher water levels could cause at least two compensating effects. First, there is a greater dilution effect due to the larger volume of water in the lake. Second, higher water levels, especially in late summer should reduce the amount of resuspension of sediment from the presently extensive 3 - 4 m silt-bottomed part of the lake. This area will be reduced significantly by Scheme B and quite markedly by Scheme C.

Since areas containing erodable materials are small relative to total lake area, since the areas possessing the largest amount of erodable materials are protected to some extent from wave-action, and since higher water levels also appear to have some counteracting effects against increased turbidity, it appears unlikely that significant increases in turbidity would take place with either Scheme B or Scheme C.

A corollary to the hypothesis that there would be no major increase, and possibly a decrease in turbidity, with increased sediment load, is that there should be some increase in the rate of sedimentation on the lake bottom. In addition, finer sediments should be deposited at higher bottom elevations because of depth increases. Such subtle changes in the nature of bottom sediments could bring about some faunal readjustments.

Turbidity in the Kakisa River

During the first year of construction, no dams would be built, and there would be no regulation of flow of the Kakisa River (UMA Kakisa Hydro-Electric Feasibility Study, May 1972). There would be excavation of river banks for intake structures and penstocks as well as dam foundation preparation. These operations could potentially cause heavy siltation of the river. However, with strict specifications for construction procedures it should be possible to effect some reduction in the severity of river siltation.

The second year of construction would involve a major reduction in streamflow and the dumping of large quantities of fill into the river from May 1 to October 1. Such procedures should result in major siltation of the stream bed. After construction is completed, provision of high flows, comparable to normally-occurring high spring flows, should remove most accumulated silt.

In the long term, turbidity in Kakisa River should be reduced. Sedimentation behind the dam should cause the river, downstream of the dam, to become clearer than it is presently.

Color

Decomposition of organic soil, especially in the west end of the lake, could bring about localized color increases, but runoff from poorly drained areas is very small compared to that from the upper watershed (i.e. Tathlina River flow). Therefore, any increase in color should be very slight.

Water Chemistry

Decomposition of vegetation and organic material and erosional effects on both organic and mineral soils should release dissolved inorganic and organic substances to the water column and to the sediments. These nutrient releases could conceivably cause short-term changes in water chemistry in localized parts of the lake, but in the long term, the water chemistry should continue to reflect the edaphic characteristics of the Kakisa River watershed. It should be remembered that "flushing time" for Kakisa Lake is only 1.1 yr and that the lake is constantly mixed. Consequently, the lake is in essence a very large widening of Kakisa River. Since both the water and the sediments which determine the water chemistry of Kakisa Lake are principally derived from the large Tathlina River inflow, it is unlikely that major differences in gross water chemistry, could develop.

It does appear, however that impoundment could cause some alteration in the dynamics of phosphorus in Kakisa Lake, because the bulk of the phosphorus in a lake system in either fixed in sediments (Lee, 1970, pp 35-36) or stored by Phytoplankton, littoral macrophytes and even zooplankton (Ruttner, 1963, p 90). Only a small portion of the total lake phosphorus is present in dissolved phosphate form. Consequently phosphate tends to accumulate in a lake system.

Phosphate released from erosion and leaching of mineral soils and from decomposition of vegetation would likely be taken up immediately by plant organisms and could cause a short-term burst of high productivity. This type of initial flush of high productivity has been noted by most researchers in the initial flooding stage of reservoirs (Neel, 1963). Whether or not this would happen in Kakisa depends on whether or not productivity at present is being limited by any particular nutrient in short supply.

Ultimately much of the initial phosphate flush would find its way into the sediments, where it would enter into the complex dynamics of phosphorus transfer between sediments and the overlying water. An overview of research into these dynamics is contained in Lee (1970). Knowledge of the intricacies of mud-water nutrient transfers is at a primitive stage, and the development of predictive models is not yet possible.

Large amounts of phosphates absorbed to soil particles eroded from the new shores of the lake would also be carried into the sediments. Since phosphorus is strongly absorbed to particulate matter, this would likely be the major mechanism by which phosphorus from the terrestrial environment would be transferred to the aquatic environment.

The most subtle and perhaps the most important change in the phosphorus dynamics of the lake would be brought about by regulation of the outflow. With greatly reduced spring outflows, there could be much greater retention of phosphorus in the system, because losses in phytoplankton, which tie up most of the free phosphates, would be greatly reduced during the spring and summer, when phytoplankton populations are high. Since this effect would occur over the life of the project it likely overshadows the short-term effects of decay of terrestrial vegetation and erosion of terrestrial soils.

Although phosphorus accumulation is generally considered the major contributing factor to the process of eutrophication, it is not clear that productivity is limited by phosphorus in all lakes. In Kakisa, there is at least some circumstantial evidence that productivity may be limited by physical factors. However, this has not been verified, and verification would require a major research effort.

Plankton

Productivity of plankton in Kakisa Lake could be influenced by such factors as the light absorption properties of the water column, nutrient conditions, and rates of loss of nutrients and plankton in the outflowing water.

A minor short-term increase in color and a slight compensating long-term decrease in turbidity from non-living sources has been predicted for a regulated Kakisa Lake and thus it seems unlikely that major changes in the light absorption properties of the water would occur. Reduction in outflow at the time of breakup, when nutrients are normally at their highest levels (Table 8), should decrease loss of nutrients to the lake and increase their availability to lake phytoplankton in the spring. Perhaps more important, reduction in spring and early summer outflow, and could allow a more rapid buildup of the plankton population. Lowered summer out-flows might also reduce the total summer loss of plankton to the outflow and increase the amount of organic material retained in the lake system, especially during wet and normal years. In dry years, this effect should be somewhat less pronounced.

Thus, there is reason to believe that impoundment and flow regulation could actually increase annual production of plankton, and could also increase the percentage of this production retained in the lake system.

Decreasing summer flows should have an effect very similar to that of a decreased annual flushing rate. The importance of the effect of flushing time has been reported by Rawson (1960b, 1961) and has been discussed earlier in this paper in the section on Lake Productivity.

Improved conditions for plankton could increase the frequency and intensity of plankton blooms. The biological significance of increased plankton blooms in a constantly agitated lake such as Kakisa is not clear. No adverse biological effects were observed during the widespread light bloom* conditions that occurred under natural conditions in August of 1972.

Bottom Organisms

Bottom Organisms of Rocky, Gravelly and Sandy Littoral Areas

Since the lake should not be drawn down any lower under regulation than under natural conditions, winter drawdown should have no adverse effects on the present rocky littoral. Higher summer levels may result in some increase in deposition of silt and organic material in the present rocky littoral which could cause some faunal shift but would be more likely to raise rather than to lower productivity in those areas.

Newly-flooded former terrestrial environments should have at least short-term potential for high productivity because of the inclusion of terrestrial organic material in aquatic environments newly-formed by flooding. However, the potential might not be fully realized because of winter drawdown, which would freeze overwintering organisms. Grimas (1961) found that there was a reduction of 70% in the regulated zone of Lake Blasjon in northern Sweden. He found that all major groups were greatly reduced in number by the effects of winter drawdown. Only the chironomid tribe Tanytarsini contained species capable of overwintering in the extreme conditions of the frozen littoral, and, of this tribe, only the species *Parakiefferiella bathophilia* was successful in the drawdown zone. The ability of all other groups, including large aquatic insects, crustaceans, molluscs and oligochaetes, to endure frozen conditions in the littoral was low to non-existent.

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* plankton clearly concentrated at surface but not forming continuous cover on water surface.

In Kakisa it is possible that one or two species of chironomids would have the ability to overwinter in the vegetated littoral. Most other possible colonizers would likely perish during the overwintering period. It is also likely that mobile animals such as crustaceans and some of the large insect larvae may migrate into newly flooded areas during summer. However, natural propagation is unlikely to occur because of winter drawdown and a new wave of colonization would have to occur each year.

It is unlikely that flooded shoreline areas of glacial till will remain productive summer habitats for indefinite periods of time. Wave and ice erosion should eventually remove the fine mineral and organic particles, creating rocky and sandy shore areas as unproductive as those presently existing.

Bottom Organisms of the Vegetated Littoral

There is extensive documentation (Frohme, 1938; Berg, 1949; MacGaha, 1952; Rosine, 1955; Grimas, 1961, 62, 64, 65; Smirnov, 1959) that the vegetated littoral is responsible for a level of production of aquatic invertebrates out of proportion to its contribution to total lake area. In Kakisa Lake, this region produces a great abundance of amphipods, caddisfly larvae, small mayfly nymphs, beetle, dragonfly and mayfly larvae, water bugs, cladocerans and copepods. Many species are not commonly found outside the vegetated zones; others are found outside the vegetated zones, but in greatly-reduced numbers.

The discussion on the effects of hydro development on aquatic vegetation indicated high probabilities of both reduction in areal extent and stem density of aquatic vegetation. Organisms found in the vegetated littoral are either totally dependent on vegetation or else derive major benefits from it. Each loss of an aquatic plant is, in effect, a loss of a certain definite area of available substrate for the organisms associated with the plant. The relationship between available substrate and number of animals is fairly direct, so it is not a gross oversimplification to state that the percent reduction in the total number of animals of the vegetated littoral would very closely correspond with the percent reduction in the number of aquatic plant stems.

From the previous discussion on the effect of hydro development on aquatic vegetation, it would not be unreasonable to expect a 50% reduction in areas occupied by aquatic vegetation and a 50% reduction in stem density in the remaining area for Scheme C in the median year. This situation would result in a 75% decrease in the total number of aquatic plant stems and likely a similar reduction in the organisms associated with them. This analysis does not even take into account the possibility of a total crop failure of aquatic vegetation which could happen from time to time with Schemes B and C. Such an event could cause instability in both aquatic plant and aquatic invertebrate communities for several years, and would likely cause further decreases in productivity.

Although Scheme C would create a considerable increase in shallow water areas in the 0 - 1 m range, harsh winter conditions of freezing and drawdown would likely limit summer productivity in those areas, especially when distances from unfrozen winter refuges are great.

In summary, fairly conservative predictive assumptions indicate strong likelihood of major reductions in the vegetated littoral fauna of Kakisa Lake.

Bottom Organisms of Silt-Bottomed Areas

Impoundment is likely to cause a shoreward shift of the presently-existing pattern of sedimentation, and an increased rate of sedimentation that could, in turn, cause a slight decrease in dissolved oxygen at the mud-water interface, but would be unlikely to cause significant changes in dissolved oxygen in the water column. It appears very unlikely that changes in the silt-bottomed areas would exceed the environmental tolerances of either of the dominant *Hexagenia* and *Chironomus* species. Two species of *Hexagenia (H. limbata* and *H. bilineata)* flourished in Lewis and Clark Reservoir under conditions of heavier siltation and greater oxygen fluctuation than in Kakisa (Swanson, 1966). The tube-building Chironominae are reported to be able to withstand very low levels of dissolved oxygen (Oliver, 1971). It is highly unlikely that they would be adversely affected by the small environmental changes in the bottom sediments caused by impoundment and regulation.

If substrate conditions control the competitive positions of *Hexagenia* and *Chironomus*, a shoreward shift in the existing pattern of siltation might allow *Chironomus* to expand into areas formerly occupied by *Hexagenia* and might force *Hexagenia* into a smaller area of suitable substrate (Tables 39 and 37). If on the other hand, the higher densities of *Hexagenia* in the shallows are related to ovipositing habits of emerged adults (Swanson, 1967), impoundment would have no foreseeable effect on *Hexagenia*.

Impoundment could conceivably benefit production in the lake system since greater retention of plankton could increase the detritus food source for both *Hexagenia* and *Chironomus*. In the very long term, of course, this type of productivity increase would also hasten the rate of eutrophication of the lake.

Bottom Organisms of Slow-Flowing Rivers

Since it appears unlikely that the depth added to the slow-flowing rivers would be sufficient to eliminate aquatic vegetation it is equally unlikely that there would be a major qualitative change in the river fauna. However, a reduction in stem density of rooted aquatics could bring about a corresponding decrease in biomass of the associated fauna. In streams with dense aquatic vegetation, such as those found in the Kakisa area, river plants provide a much greater area of available substrate than does the actual streambed. Therefore, thinning out of the vegetation constitutes a reduction in available substrate.

The probability of substantially thinning out the rooted aquatic vegetation appears relatively high for Scheme C where depths of rooted aquatics would be close to their maximum depth tolerance of 3 to 4 ft (9.75 to 13.10 m). The thinning out effect of Scheme B might be much less, and if so that scheme would constitute much smaller disturbance than Scheme C.

Bottom Organisms of Tathlina River

An upstream shift in the zone of sediment deposition in the mouth of Tathlina River could cause some faunal shifts in the area of the river influenced by lake levels. The area involved is not great and the existing invertebrate fauna appear meager on the basis of analysis of stomach contents of fish caught in the area and on the basis of casual collection. Therefore, effects of changes to the Tathlina River bottom fauna should have only a slight effect on the total lake ecosystem.

Bottom Organisms of Kakisa River Upstream of Dam

Settling of silt and plankton overflow from Kakisa Lake in the reach of the Kakisa River above the dam should bring about radical changes in the properties of this part of the stream. Conditions should deteriorate for the fast-water, rock-inhabiting forms presently in the stream while conditions for filter-feeding clams could improve considerably. As silt and organic detritus start to accumulate, there should be a major expansion of the chironomid fauna. Once the present rock bottom becomes coated with an adequate amount of silt, it is highly likely that the burrowing mayfly *Hexagenia* could establish itself and gradually increase to a very high density over a number of years. Swanson (1967) documented an expansion of *Hexagenia* to a very high number in Lewis and Clark Reservoir. He concluded that small, relatively-shallow impoundments located on silt-laden river systems appear to provide excellent habitat for burrowing mayflies.

The major factor limiting establishment and expansion of *Hexagenia* above the dam is the possibility of thermal stratification and attendant low dissolved oxygen at the mud-water interface.

Development of high populations of chironomids, clams and burrowing mayflies could provide good feeding opportunities for fish from the lake. At the same time, development of high bottom populations of chironomids and burrowing mayflies could result in swarms of emerging adults which might annoy visitors to the Lady Evelyn Falls area. Swarms of *Hexagenia* are a major problem in the Mississippi River region (Fremling, 1964). Suber (1954) and Fremling (1960) found that impoundments increased the available habitat for *Hexagenia*.

Bottom Organisms of Kakisa River Downstream of Dam

In the second year, construction should result in low flows, high turbidity and heavy sedimentation. Low flows and high turbidity might also result in elevated river temperatures. The present stream fauna is adapted to conditions of swift flow, moderate temperature and clean gravel and rock substrate. Thus, the fauna appears to be highly susceptible to the types of disturbances that should occur. A number of species might be unable to survive those disturbances.

It is likely that recolonization would take place in the river below the dam, once the silt accumulated on the river bottom is flushed out, after project completion. Recolonization might be a rather slow process, however, since the continuity of the fauna of the Kakisa River drainage system is interrupted by Kakisa Lake. The lake likely provides a formidable barrier which discourages the fauna of Tathlina River from colonizing Kakisa River.

It is also possible that even sensitive species might not suffer total mortality, and small pockets might survive to recolonize the stream. A final possibility is that effects of siltation on the bottom fauna might decrease with distance downstream from the construction site. Since stream invertebrates with both flying and non-flying adult phases continually colonize upstream environments to offset the effects of downstream drift (Hynes, 1970, pp 155 and 268), this type of recolonization is very probable.

Once the fauna is reestablished, it appears unlikely that the former level of productivity would be sustained, since considerable nutritive losses would occur because of settlement of organic material behind the dam and reduction of plankton and detritus overflow from the lake, and consequent loss of both a direct source of food and a source of nutrients. Lowered productivity of bottom organisms in the river, caused by reduced plankton supply, is the corollary of increased productivity in the lake caused by increased plankton retention there.

Fisheries

Spring Spawning in Inflowing Streams

Even with slightly reduced stream velocities in spring, it seems unlikely that settling of silt and organic debris fine enough to damage eggs of spring spawners would occur. Lower spring stream velocities could reduce the amount of scour that takes place, however. In addition, reduced stream velocities, especially during mid and late summer, should promote greater silt accumulation. As a result a greater accumulation and reduced scour of silt, certain spring spawning areas, which are only marginally suitable under natural conditions and which depend upon spring scour for maintenance, could conceivably become unsuitable under lake level regulation. It is difficult to predict how widespread that occurrence might be because there are no quantitative data available on flow and sediment transport.

In most of the slow-flowing streams, there should be adequate vegetation for successful pike spawning. Flooding of emergent vegetation may create some new spawning areas.

Stickleback, which also have a vegetation requirement for successful spawning, should also be able to maintain spawning areas.

Spring Spawning in Kakisa River

Higher water levels and curtailment of high spring flows may accelerate siltation in the outlet area. At present, large areas undergo siltation. It is reasonable to expect that with lower velocities and less fluctuation in velocity, this phenomenon will become more widespread. It appears that the outlet area is used as a spawning area for white suckers and spottail shiners, and likely for other species as well. Siltation should have some detrimental effect on spawning of those species in that area.

The project could cause spawning problems downstream of the proposed dam site. During the first year of construction excavation along the river banks could cause siltation, but it may be possible to prevent total mortality of eggs if extreme care is taken to avoid unnecessary removal of vegetation, unnecessary road construction and careless excavation and dumping. Flow cutbacks and construction in the river channel in the second year of construction would seriously threaten the survival of eggs and fry. It may be possible to take some steps to reduce the impact of siltation, but it would nevertheless appear that the combination of low flow and high turbidity and sedimentation might cause heavy and perhaps even total mortality of eggs and fry during the second year of construction. Spawning problems during the second year of construction should be particularly acute for arctic grayling which are characteristically found in clear water (McPhail and Lindsey, 1970, p 127).

Once the project is completed, it should be possible to maintain spring spawning in Kakisa River. Since the plant is to be designed for continuous, rather than peaking, power, adequate flows would usually be provided under normal operating conditions. As long as downstream flows are managed to prevent exposure of riffles and to prevent temperature fluctuations exceeding maximum naturally occurring fluctuations, it should be possible to avoid major problems. This would require provision of compensatory flows during shutdowns or major cutbacks.

The success of future spring spawning might be affected by the degree of damage caused to the adult populations of fishes during the construction period. There is reason to suspect that walleye and pike form permanent resident populations in the stream in view of the rather formidable barrier that fast water at the river ford prevents to upstream migration. Longnose suckers were just barely able to pass this barrier in spring, largely because they could hold on to rocks with their mouths. A pike found near shore in the ford area, when frightened from its refuge into the current, was instantly swept downstream. Walleye would probably fare only slightly better. Bishop (1967) also suggests that there is a resident population of sub-adult (less than 6 year old) arctic grayling in Kakisa River, and that lack of catch success after late June is caused by a change in feeding habits which makes the lures used by fishermen unattractive to the fish. Thus it is seen that there is considerable potential for damage to stocks of adult and sub-adult fish of all major species, including the much-sought grayling, during the second year of construction.

Spring delay in warmup of Kakisa River could cause some delay in spring spawning. Alternatively, spring spawning might be reduced just downstream of the power plant discharge and might gradually become more prevalent downstream as river temperature rises because of heat exchange with the air. Spawning delays could result in poorer fish growth in the first summer of life and could thus contribute to poorer overwinter survival. However, there is no question of delayed warmup of the river causing catastrophic changes in fish populations because all the major spring-spawning species have distributions extending to and beyond the Arctic Circle where breakup occurs very late.

Fall Spawning in Kakisa Lake

It has been seen that for the period of record, Scheme B causes an average of 1.3 ft (0.40 m) and Scheme C causes an average of 1.4 ft (0.43 m) more drawdown than Scheme A. Maximum difference in drawdown (Table 37) is 2.3 ft (0.70 m) between Scheme B and Scheme A (1967-68) and 3.3 ft (1.01 m) between Scheme C and Scheme A (1969-70). Average limit of drawdown is 723.9 ft (220.66 m) for Scheme A, 724.7 ft (220.60 m) for Scheme B and 726.1 ft (221.31 m) for Scheme C. In the confirmed spawning areas that were examined, suitable spawning substrate did not usually exist below elevation 716 ft (218.23 m). However, along the south shore, towards the west end of the lake, possible spawning areas as low as elevation 712 ft (217.01 m) were found, but spawning was not confirmed.

Assuming that the lower limit of spawning remains fixed, Schemes B and C increase the average vertical extent of available spawning areas by 0.8 ft (0.24 m) and 2.1 ft (0.64 m), respectively, by raising the upper limit of spawning. However, with higher average water level, sedimentation could occur on parts of the existing hard bottom and could raise the lower limit of spawning. If this occurs, spawning areas might actually be reduced, because the shallow zones of the lake would shrink in area (Table 36 and 37) after water levels were raised.

Precise information on the depth distribution of spawning products of lake whitefish and ciscoes is not contained in the biological literature. Most descriptions of whitefish spawning are anecdotal and generally indicate spawning on rocky or gravelly shoals. Indirect evidence of the probable distribution of whitefish and cisco spawning products can be inferred from incubation studies on the two species. Price (1940) found that normal incubation of whitefish eggs required a temperature range of 0.5°C (32.9°F) to 6.0°C (42.8°F), with an optimum temperature of 0.5°C. Thus there is strong evidence that optimum conditions for survival occur just below the ice sheet in shallows of lakes or in streams. Length of time of 50% hatch decreased from 99.14 days at 0.5°C to 73.95 days at 2°C (35.6 F) to 50.03 days at 4°C (39.2 F). Thus, it is seen that very small changes in temperature caused marked shortening of egg development time.

Bidgood (1973) speculated that selection favors those whitefish that spawn in shallow water, because incubation temperatures less than 2°C are required to prevent whitefish from hatching under the ice (at a time of zooplankton scarcity) in the Alberta lakes (Buck and Pigeon) he studied. The temperature situation could be even more critical in Kakisa Lake, because ice cover lasts about 6 weeks longer. If whitefish in Kakisa have similar temperature-incubation period characteristics as those of Pigeon and Buck Lakes, temperatures of approximately 1.5°C might be required for successful reproduction. With an under-ice thermal gradient of approximately 0.8°C/m (0.44°F/ft) (Fig 5), the viable zone, according to the criteria of Bidgood, would extend down approximately 2 m (6.56 ft) below the bottom surface of the ice sheet. Since winter drawdown under natural conditions averages 1.8 ft (0.55 m), it can be seen that each additional foot of drawdown could freeze out a substantial proportion of viable whitefish eggs. However, even the largest anticipated drawdown of 4.2 ft (1.28 m) is unlikely to freeze all viable eggs. It should be noted, though, that drawdowns much larger than those anticipated could occur in future if deliberate attempts are made to use up carry-over storage when runoff predictions for the spring are favorable. If this were to be done, all eggs in the viable zone could be frozen and killed.

Colby and Brooke (1973) found that ciscoes developed normally within a temperature range of 2°C to 8°C (35.6°F to 46.4°F), with optimum development at 5.6°C (42.1°F). The study also showed that 90% mortality occurred at incubation temperatures of 0.5°C (optimum temperature for whitefish). This suggests that favorable spawning beds for ciscoes in Kakisa would occur at greater depths than those of whitefish and consequently might not be greatly affected by slight increases in overwinter drawdown.

Fall Spawning below Lady Evelyn Falls

During the second year of construction, the silt-producing activities at the construction site could have some adverse effect on downstream whitefish spawning areas near Beaver Lake. If the main silt-producing operations were terminated by early September, and if large flows were passed downstream at that time, it might be possible to remove accumulated sediments prior to spawning (mid September. Field observations of the condition of spawning beds might be desirable before such measures were taken.

Once the project is completed, normal operation of the turbines should result in more than adequate flows to preserve incubating eggs near the river mouth. In the event of extended winter shutdowns, freezing of spawning gravels might occur. It should be possible to combat this situation by providing a small compensatory flow approximating those winter flows naturally occurring under unregulated conditions in an average year.

Survival and Growth of Fish In Kakisa Lake

i) General. Quantitative prediction of changes in fish populations caused by hydro development is a problem of overwhelming complexity. Techniques for the analysis of phenomena of population dynamics, associated with subtle changes in the environment, are not sufficiently developed, for systems involving large numbers of species, to be of any use for predictive purposes.

In the present situation, one is limited to the approach of describing changes to major components of the system and pointing out, in a very general way, how these changes might affect other components of the system.

The writer has concluded that impoundment and regulation could cause two significant changes to the lake ecosystem. First, there is strong evidence for a significant reduction of aquatic vegetation. Second, there is the possibility of causing some disruption to successful spawning, especially to fall-spawning whitefish and ciscoes. Of the fall-spawning species, the cisco is likely one of the most important species of the food chains of the lake, since it is an efficient converter of energy, being a plankton feeder, and is also the principal prey species of walleye and pike.

ii) Survival of Fry, Subadult and Forage Fish. In the descriptive first section of this paper, it was pointed out that there is a strong association of juvenile walleye, pike, whitefish and white suckers with the vegetated littoral of the lake. It would also seem likely that the vegetated littoral areas are important habitats for fry and forage fish, although systematic collection of data to prove this has not been made. Reduction of the vegetated littoral should significantly reduce the food supply for fry, subadult and forage fishes.

Reduction of food supply and area of habitat for subadult fish could through lowered growth rates delay their recruitment into the adult population. It could also reduce the numbers recruited into the adult population. It is not clear that lowered recruitment necessarily means a reduction in the commercial value of fish taken. At present, it appears that recruitment in Kakisa Lake is high, since growth rates are generally low, relative to indicators of productivity such as weight of catch per "standard gang", weight of bottom organisms per unit area and weight of plankton per unit area. Therefore, lowered recruitment could conceivably improve growth rates, resulting in fewer but heavier marketable fish, provided food supply is maintained.

Of the forage fish, the stickleback is likely the most heavily dependent on aquatic vegetation, particularly during the reproductive phase. Ciscoes on the other hand have virtually no obligatory dependence on the vegetated littoral, being gravel spawners and mainly planktonic feeders. Chub and spottail shiners are also gravel spawners, but appear to derive significant nutritional benefits from the vegetated littoral, and are somewhat intermediate between sticklebacks and ciscoes, as far as requirements for aquatic vegetation are concerned.

The cisco, the chief prey species of walleye and pike, could on the one hand suffer reproductive problems from increased water level fluctuation and on the other hand could benefit if zooplankton in the lake increases, caused by restriction of outflow in early and mid summer. Since the magnitudes of both the possible detrimental and possible beneficial effects of development on ciscoes are extremely difficult to predict, it is very hard to say whether the detrimental or beneficial effects would predominate.

iii) Survival and Growth of Walleye and Pike. During the first year or two of life, walleye in Kakisa Lake appear to remain in offshore areas well away from the vegetated littoral. Efforts to secure specimens near shore by seining in late June and early July were unsuccessful. This is consistent with the results of Priegel (1970), who found walleye to be pelagic during the first year of life.

However, walleye were found concentrated near vegetated areas during the subadult phase. Therefore, it would appear that growth and survival during that phase (approx 2 - 6 yrs) may be strongly linked with the properties of the vegetated littoral. Shrinkage of that zone could cause reduction in growth rate and/or reduction in recruitment to the adult population. As pointed out earlier, a numerical reduction of the adult population need not imply a decrease in the value of the commercial fishery, since growth rates of survivors could increase to supply as many or more kg/ha.

Adult walleye seem to have very little dependency on aquatic vegetation. They range the lake freely, usually seeking out the pelagic cisco. Annual production of marketable walleye might thus be strongly tied to the continued success of the cisco, which could potentially be either beneficially or adversely affected by the development.

Both fry and subadult pike seem to be much more strongly tied to the littoral than walleye. The presence of extensive shallows in Kakisa may explain the exceptionally good growth rate of pike in their first few years of life. Reduction of vegetated areas should have some effect on pike recruitment. Young pike might be more adversely affected than young walleye by reduction of the vegetated littoral. This could conceivably improve the competitive position of walleye to some extent.

Adult pike, like adult walleye, ranged throughout the lake in search of ciscoes as evidenced by catch records and food analysis. They should not be as strongly affected as subadults by reduction in the vegetated littoral, although they might, like walleye, be sensitive to population changes of ciscoes.

Both pike and walleye should be sensitive, to some degree, to changes in growth rates and/or population sizes of other prey species, such as troutperch, sticklebacks and chub. Since these prey species seem to derive at least some benefits from the vegetated littoral, it is not unreasonable to suspect that reduction of the littoral could affect them and in turn affect piscivorous walleye and pike that feed upon them. A simultaneous decline in ciscoes, troutperch, sticklebacks and lake chub would almost certainly reduce production of walleye and pike.

iv) Survival and Growth of Whitefish and White Suckers. Lawler (1965) stated that whitefish are usually found in the deep areas of lakes, and that there is generally a migratory movement away from shore in spring and towards shore in fall. It would appear that, in such cases, whitefish are following a favorable temperature zone. Reckahn (1970) claimed that whitefish fry in lake Huron follow the 17°C (64.4°F) isotherm throughout summer.

In Kakisa Lake, there was no concentration of whitefish in deeper areas of the lake. Some of the largest specimens taken in midsummer were in very shallow vegetated areas, especially in the west end of the lake. It is possible that, in the isothermal Kakisa Lake, whitefish have no opportunity to exercise temperature preferences, and therefore show no depth-selection. Feeding data (Fig.11; Appendix VI) indicate that organisms from the vegetated littoral and from vegetated river areas constitute an important part of their diet. Reduction in the vegetated littoral and thinning of aquatic vegetation, could result in some reduction in total annual whitefish production.

There was a definite concentration of subadult whitefish in river and vegetated littoral areas. These areas appear to be the major rearing areas and reduction in extent and density of rooted aquatics could affect growth and/or recruitment into the adult population.

Greater variability in spawning success caused by increased overwinter fluctuations could also have an effect on recruitment.

Both subadult and adult white suckers were found almost exclusively in vegetated areas. Fry were also heavily concentrated in those areas, although they were also found along rocky shores. The diet of subadult and adult white suckers consisted mostly of forms inhabiting the vegetated river and lakeshore areas. Only very large adults were found feeding outside the vegetated zone. Thus, it can be seen that white suckers show a general affinity for the vegetated areas of the lake, and it is possible that they would be adversely affected by reduction of those areas.

Siltation of the outlet area could cause a substantial loss of spawning area for white suckers that could conceivably affect adult population levels.

Damage to white sucker population could conceivably benefit whitefish population because both species are competing for similar food resources.

Survival and Growth of Fish Downstream of Dam

Reduced flow and heavy siltation, caused by construction in the second year, could put severe stress on adult fish as well as on fry and eggs. It is quite possible that heavy mortality of adult fish could occur. Adults may be capable of tolerating high turbidity for one season, but the combination of high turbidity and low flow could prove lethal. Provision of the highest possible flows during construction could alleviate the problem to some extent by diluting the turbid flows, by preventing temperature excesses and by providing high levels of dissolved oxygen.

Serious damage to adult population in the river would retard recovery of the fishery after the project was finished. Resident populations of walleye, pike and possibly subadult grayling would appear more susceptible to damage than longnose sucker and lake whitefish which only use the Kakisa during spawning.

Restriction in flow and heavy siltation of the second year of construction could have adverse effects on the natural bottom fauna. It might take a number of years for the bottom fauna to recover from the shock of the construction period. During the period of recovery, the supply of fish food could be considerably reduced.

Since the downstream supply of plankton is apt to be restricted by impoundment, the direct supply of this material to fry fish, the supply to bottom invertebrates and thence to larger fish, and the nutrients supplied through decomposition are likely to be reduced. Thus, there could be some long-term decrease in fish productivity in the Kakisa River, downstream of the dam.

If care is taken to prevent downstream environmental shocks, it should be possible to restore, qualitatively at least, the natural fish and invertebrate fauna.

Waterfowl and Shorebirds

Early Spring

Ice blockages in the outlet area, caused by obstruction of the normal free flow of water and ice floes, could greatly impair the utility of the outlet area as a feeding zone for ducks and shorebirds in spring. Impoundment of Kakisa River to the level of Kakisa Lake would make most of the stretch of river between the lake and the dam too deep for feeding ducks.

Summer Breeding Season

Munro (1967) attributes abundance of nesting sites for ground-nesting ducks to the number of areas created by interspersion of emergent vegetation and small bodies of water. Munro's description of excellent duck nesting habitat coincides quite closely with a description of terrain to the west of the lake. The chief limiting factor on the utility of that area for duck nesting is the possibility of high early summer lake levels, which can cause flooding of already established nesting sites, even under natural conditions. Impoundment of Kakisa Lake should cause this type of flooding to become a certainty rather than a possibility.

There could be some nesting activity along the newly established western shoreline of the lake. However, available habitat appears to be much less than under natural conditions. Moreover, nesting sites in those areas would be very susceptible to small variations in water level.

The eastern shore of the lake is not as suitable for ground nesters as the western shore. Most potential sites occur along river banks and on rivermouth islands. Little River, with low banks, could experience extensive flooding of nesting sites. Sites on the islands in the mouths of Muskeg and Tathlina River should suffer total inundation, although those sites do not appear to have nesting populations of any great significance. Along Muskeg River only nesting sites located in the low-lying willow vegetation on the inside of meanders would be affected.

Tree-nesting sites close to rivers could also suffer from the effects of impoundment. However, if a few of the large trees killed by impoundment are left standing it might be possible to preserve nesting areas for goldeneyes, at least on a short-term basis. There is also evidence (Cowardin et. al., 1967) that mallards are capable of using tree and stump-nesting sites in areas of flooded forest.

From the waterfowl point of view, it might be worthwhile to set aside small areas of mature dead trees for nesting sites. However, this may be aesthetically objectionable to some, and could cause other problems later on, such as floating logs in the lake.

Late Summer and Fall

High water levels in late summer and fall would totally inundate the two points in the west end of the lake used as resting areas for migrating geese. They were observed to be the only areas near the lake heavily utilized by Canada geese.

Reduction in aquatic vegetation throughout the lake would not likely affect waterfowl use because even under conditions of reduced aquatic vegetation, there would likely be a surplus. Even if a total crop failure of rooted aquatics occurred in the lake, there would likely be fairly substantial amounts of rooted aquatics in rivermouths and in the outlet area.

Rare Predatory Birds

Some of the tall nesting trees near shore, used by bald eagles and ospreys, could be killed by the inpoundment scheme. It is not known whether this would have any immediate short-term effect. Birds would probably continue to occupy the nesting trees for several years after the trees died, if they were left standing. Eventually, the birds would be forced to move some distance away from the water in to new nesting trees. It is not known what effect these types of disturbances have on eagles and ospreys.

Furbearers

Beavers

All of the good beaver habitat west of the lake, which is capable of supporting at least six permanent colonies would be flooded. Most willow vegetation along Little River would be killed by higher sustained water levels. On Muskeg River most of the willow on the inside of meanders should be killed but substantial areas of aspen should remain intact.

Beaver colonies in the west end of the lake would be subjected to severe conditions of water level fluctuation. Their bank lodges or bank burrows would be flooded throughout the spring and summer. Beavers in Little River and in the mouth of Muskeg River should be subjected to similar problems. Only the beaver houses located well upstream on the Muskeg River would be unaffected.

In view of the certain event of extensive habitat destruction and the likely event of unfavourable water level fluctuations, it is quite possible that beavers would be eliminated from the west end streams and at least from the lower reaches of the east end streams.

Other Furbearers and Small Game

The areas immediately adjoining the lake have higher species abundance of plants and greater production than the black spruce muskeg which dominates the larger area. Consequently, productivity of small herbivores, such as snowshoe hares, spruce grouse, red squirrels, mice and voles should be greater in those areas than in the black spruce muskeg. Populations of predatory furbearers, such as lynx, mink, marten and weasel, should be correspondingly high. Elimination of many of the more diverse habitats found around the lake and deterioration in the quality of much of the remainder should have some adverse effect on the populations of furbearers.

The muskrat is not exceptionally common around Kakisa Lake, possibly because of scarcity of protected shallow water areas with extensive emergent vegetation. Under impoundment, shallow water areas may increase, as the low lying areas in the west and along Little River are flooded. Thus potential habitat could increase. However, sites suitable for houses or bank burrows might not increase accordingly. In addition, winter drawdown should adversely affect survival in newly-flooded areas. Therefore, there may be no increase in the muskrat population, and decreases are even possible.

Big Game

Moose

Either Scheme B or C should kill virtually all willow vegetation, the principal winter browse of moose, in the vicinity of Kakisa Lake.

As a result, the ability of the area to support moose should be impaired.

Flow regulation could prevent spring flooding of low willow area around the mouth of Kakisa River and could conceivably allow succession to aspen and white spruce to take place. That stretch of Kakisa River is suitable for overwintering moose, and succession to more mesic species would reduce its suitability over time. The dynamics of the area are not clearly understood, however, since they have been investigated primarily by aerial reconnaissance.

Wolves and Bears

Damage to productive areas near the lake should cause at least some reduction to the food supply of bears and wolves, and could have some adverse affect on those species. However, total destruction of wolf and bear habitat would not occur, in contrast to the case of such animals as beavers.

Aesthetic Considerations

Damage to Vegetation

The most severe aesthetic impact on the area would be damage to terrestrial vegetation, which would be particularly unappealing if dead trees and brush were left standing.

The low-lying wetlands in the west end of the lake are particularly attractive, in the writer's opinion. The nature of the area would be radically altered by raised water levels. Streams would be drowned out and widened to become extensions of the lake, riverbank and lakeshore tree communities would be killed and sedge meadows would be flooded.

The pleasing vegetation along Muskeg River and Little River would suffer significant mortality as would tree vegetation in low-lying rivermouth areas of Muskeg River and Tathlina River. Trees on deltaic islands on Muskeg and Tathlina River would be very heavily damaged.

Many large mature trees of the north shore and of parts of the east shore would be killed, in many cases back to the boundary of the muskeg.

The net effect of damage to terrestrial vegetation would be a general deterioration of the scenic appeal of the area. If trees were not removed, the effect would be particularly dismal.

Scheme B results in significantly less area of vegetation damage. However, the aesthetic impact of the damage would be as serious as that of Scheme C, when viewed from the water, if dead trees were not cleared away. If clearing were practiced, Scheme B could have significantly less aesthetic impact than Scheme C.

Flooding of Geomorphological Features

The impoundment scheme would also result in the loss of some aesthetically-pleasing geomorphological features. The scheme would inundate the Kakisa River valley above the falls. The river valley itself is very attractive and in addition, a picturesque set of cascades is found just a short distance above the falls. Although a less imposing geomorphological feature than Lady Evelyn Falls, the cascades would be considered by some people to be equally appealing. Other geomorphological features which are less imposing, but nevertheless attractive, are the deltaic islands of Muskeg River and particularly of Tathlina River that would be almost totally flooded by

Scheme C and rather heavily flooded by Scheme B. Similarly, the sandbar points of the west end of the lake would be totally flooded by either scheme.

The three streams in the west end of the lake would be drowned out by raised water levels and would lose most of their stream-like qualities. They would become, for all intents and purposes, arm-like extensions of the western part of the lake. Little River would also be similarly affected, but not quite to the same extent as the western rivers.

Finally, beach areas, which normally become exposed along the north shore and parts of the south shore during summer, would remain inundated throughout summer. This may be only a small aesthetic consideration for many people, but may be valued somewhat more by others.

Wildlife and Wilderness Values

The project would definitely downgrade Kakisa Lake as a wildlife area. Such a disturbance can be though of as a serious aesthetic impact.

Because of the disturbances caused by raised water levels and because of the presence of hydro-electric structures and power lines in the Kakisa River area, the appeal of the Kakisa region as an area of semi-wilderness would be considerably reduced.

Construction Damage

The project could require extensive excavation for fill, clearing of timber and building of construction roads in the Kakisa River area. Much of the damage created during construction could be semi-permanent and could be construed as a loss of aesthetic appeal.

If water levels of the lake were not adequately controlled during the second year of construction, flooding of land above design full supply level could occur. Such flooding could cause unnecessary damage to tree communities and wildlife. It should be possible to avoid such damage by making provisions in the contract specifications for special construction procedures in the event of a wet year.

Human Ecology

Since hunting, fishing and trapping constitute a way of life for the people of the Kakisa Lake area, it is obvious that changes involving fish and wildlife or access to these resources could affect local residents.

Ice in the outlet area could interfere with spring waterfowl hunting, which is strictly-speaking illegal, but which is generally recognized as a traditional right and an important source of dietary variety. Ice could also delay boat access to fishing areas during the major fishing season on Kakisa Lake. Higher water levels should cause a general deterioration in hunting and trapping in the immediate vicinity of the lake.

Impairment of hunting around the lake may be an important consideration for native people. Impairment of trapping may also have some effect, but this effect may be damped by the fact that most furs are taken in areas quite distant from the lake.

After impoundment, the fishery will be subjected to more unstable environmental influences than before impoundment. It does not appear that those influences would result in a major decline or collapse of the fishery. However, some impairment is possible. It seems unlikely that the level of impairment that might be suffered would be felt by local people at the present level of exploitation of the fishery. However, the effects could come into play at a possible future higher level of exploitation, under more intense management. Thus, damage to the fishery is unlikely to cause losses of standard of living under present conditions, but could conceivably affect the ultimate potential income derived from the fishery.

Apart from purely economic considerations, local residents, whose entire lifestyle centers on pursuits closely linked with their natural environment, could suffer a rather acute loss of enjoyment of their immediate environment if visible damage occurs.

Perhaps most significantly, disturbance caused by construction personnel and by a sudden and short-term increase in available income, could be very upsetting to the social order of the village. The local residents would enjoy no lasting benefits from employment on the project. Such short-term employment at fairly high salary rates may only make it more difficult to return to the previous way of life.

In the long-term, tourism may benefit local residents more than short-term gains in income resulting from development. However, development of the hydro potential of the area could have some adverse effect on tourism, because of the aesthetic impact and possibly because of the impact on the sport fishery.

The sport fishery in the Kakisa River, though perhaps not a major one in terms of biomass of fish, is nevertheless cherished by residents of N.W.T. and tourists alike. Although the project is unlikely to eliminate this sport fishery, a decline could occur in the first few years after completion of the project and long-term productivity may be lowered.

Raising the water level of the lake should cause at least three recreational benefits. Raised water levels would make access to the lake simpler and less hazardous, by deepening the channel out to the lake and by reducing the density of aquatic vegetation in the channel. Similarly navigation near shore would be easier. Finally, deeper water in Tathlina River would provide much better boat access to a very attractive area of rock formations and rapids about a mile up the river.

SUMMARY

General Description of Kakisa Ecosystem

1. Kakisa Lake is shallow (mean depth 3.8 m), warm (18 - 20°C in summer), isothermal, near-eutrophic and high in dissolved oxygen (near saturation year round).

2. Except for the high escarpment along the south shore, the land surrounding the lake is generally low in relief and the lake is subject to strong wind-action.

3. Turbidity of the lake is high and color is moderate. Of the streams associated with the lake, only Tathlina River is markedly turbid.

4. Shores are generally rocky, sandy, gravelly and are noticeably unproductive. Most of the lake (85%) is silt-bottomed.

5. Aquatic vegetation covers approximately 13% of the lake and is concentrated in the east and west ends of the lake in water less than 3 m deep. Aquatic vegetation is dense in all streams other than Tathlina River, where it is totally absent.

6. The fauna of silt-bottomed areas of the lake is dominated by the large burrowing mayfly, *Hexagenia limbata* and the large tube-building chironomid, *Chironomus* (probably *plumosus). Hexagenia* cominates in shallow areas, whereas *Chironomus* dominates in deeper parts of the lake. Both genera are found in all silt-bottomed areas of the lake.

7. The fauna of vegetated regions, especially rivers, is much more diverse and abundant than the fauna of silt-bottomed areas.

8. Standing crop of plankton is moderate.

9. Walleye, pike, whitefish and white suckers are the major large fish species in the lake. Ciscoes are by far the most important prey species

in the lake. Troutperch are important prey species during their spawning runs near Tathlina River in spring. Nine-spine stickleback are consistently consumed throughout the summer.

10. Whitefish and ciscoes are heavily parasitized by the cestode *Triaenophorus crassus*.

11. Subadult fish of the four major large fish species are concentrated in areas of rooted aquatic vegetation.

12. Whitefish and white suckers derive significant nutrition from invertebrate organisms from vegetated areas.

13. Major spawning of walleye was observed in the Muskeg River, and this stream appears to be their major spawning stream whereas pike spawned in all vegetated streams. White suckers appear to spawn heavily in Kakisa River near the lake, in Tathlina River and possibly in Little River. Muskeg River seems to be a minor spawning stream for white suckers. Tathlina River is an important spawning stream for troutperch and is likely important for spottail shiners and lake chub.

14. Major spawning areas for fall spawning whitefish and ciscoes are along the rocky shores of the lake. Tathlina River is the only inflowing stream used by fall spawners.

15. Large walleye and pike are almost exclusively piscivorous and range throughout the entire lake at all depths. Smaller walleye and pike have a larger invertebrate component in their diet.

16. Large white suckers are found mostly near river mouths in vegetated areas. Large whitefish are frequently found in those areas but are also found regularly in deeper areas.

17. The downstream fishery consists of arctic grayling, walleye, pike and longnose suckers. Walleye and pike probably have resident populations.

Grayling and longnose suckers migrate up Kakisa River to spawn. There are indications that a population of subadult grayling is resident in the river.

18. Spawning of grayling downstream of the Falls seemed to occur between May 15 and June 1. Spawning of walleye, pike and white suckers occurs mainly after June 1. Spawning of those species in Kakisa River was one to two weeks later than in the rivers flowing into Kakisa Lake, probably because of lower water temperature.

19. Growth rates of walleye and whitefish are in the low to middle range of those of the Saskatchewan lakes studied by Rawson, but are higher than growth rates for Great Slave Lake. Growth rates of pike are very good, especially in the first two years of life, when they exceeded those in every Saskatchewan Lake studied by Rawson.

20. Standing crop of fish as measured by "standard gang" catch, averaged 87.4 for 29 net sets. This "standard gang" catch is higher than those of all but one of the Saskatchewan lakes studied by Rawson.

21. Kakisa Lake is as productive as the mesotrophic lakes on the margin of the Shield in Saskatchewan (La Ronge, Amisk) studied by Rawson.

22. The most productive wildlife habitats are found at the east and west ends of the lake in the vicinity of the slow, inflowing streams. They are the only available habitats for beavers and waterfowl in the general vicinity of the lake and they also contain virtually all available moose habitat. Productivity of herbivorous animals in the low-lying habitats at the east and west ends of the lake is probably of significance to lynx, marten, mink and weasel and of marginal importance to bears and wolves.

Probable Environmental Effects of Hydro Development

1. Raised water levels would create extensive areas of dead willow, aspen and white spruce, which would constitute at best an aesthetic loss, if the dead vegetation were removed, and at worst a major eyesore and fire hazard (trees killed by water table effects), if dead vegetation were left standing. Damage to lakeshore and riparian trees, in terms of linear miles, would be extensive. Thirty-five to 40 mi (64 km) of lakeshore trees and at least 20 mi (32 km) of mainstem riverbank trees (40 miles if both banks are counted) could suffer mortality.

2. Most good wildlife habitat in the Kakisa Lake area occurs in areas that would be adversely affected by raised water levels and damaging water level fluctuations. Wildlife would be affected both by destruction of vegetation and by the direct adverse impact of flooding and water level fluctuations at critical times of the year, such as the overwintering and reproductive periods. Most affected would be beavers, waterfowl, moose, snowshoe hares, and small mammals. Predators, including all major furbearers, should also be affected.

3. Use of the Kakisa area by migrating waterfowl would be affected by deepening of the Kakisa River spring-feeding area for ducks and by inundation of the fall-staging area for Canada geese on the points in the west end of the lake.

4. As viewed from the water, aesthetic impact of Schemes B and C would be about equal, if no clearing were practiced. With clearing, Scheme B would have less adverse aesthetic impact than Scheme C.

5. Areal extent of damage to vegetation and wildlife would be significantly greater with Scheme C than with Scheme B.

6. Reduction of high spring flows could reduce the extent of spring floods on Kakisa River, making conditions less favorable for willow and more favorable for aspen and white spruce in the lowest reaches of Kakisa River near Beaver Lake. This could eventually eliminate an area of winter browse for moose.

7. Blockage of the downstream passage of lake ice by impounding structures could delay lake breakup. Obstruction of the outlet area with ice could reduce its utility to spring waterfowl. Delay in breakup of the lake could reduce annual production in the lake. Percent reduction could be as much as 10 - 15 % per week delay in the optimal productive period around summer solstice. In years of early (May) lake breakup, percent reduction in annual production would be substantially less.

8. Higher water levels would reduce the area of the littoral, shallow enough to support aquatic vegetation. In the median year of record, this reduction would have been approximately 30 - 40% for Scheme B and 50 - 60% for Scheme C. In a year when maximum storage potential is realized, such as would have occurred in 1965, reduction in area of vegetation would have been 50 - 60% for Scheme B and only slightly more for Scheme C.

Increased winter drawdowns should also decrease the areal extent and density of rooted aquatics. Total crop failures appear possible when a year of maximum drawdown is followed by water levels, near full supply level, in the following season.

9. Increases in water levels should not be sufficient to prevent growth of rooted aquatics in reaches of streams affected by lake levels, with the possible exceptions of Little River and River 2, but they could cause thinning out of aquatic vegetation.

10. Reduction in density and extent of rooted aquatics should cause a corresponding reduction in the associated rich and abundant invertebrate fauna.

11. Reduction in organisms in vegetated areas could reduce annual production of fish such as whitefish and white suckers, which derive significant nutrition from that food source.

12. Reduction in organisms from the vegetated areas could affect annual production of troutperch, sticklebacks, spottail shiners and lake chub which probably derive a significant portion of their nutrition from those areas. Those species are in turn utilized by piscivorous walleye and pike.

13. Rate of growth and/or recruitment into the adult population of sub-adult walleye, pike, whitefish and white suckers could be retarded by shrinkage in vegetated littoral habitat.

14. Annual production of large, marketable walleye and pike, which do not depend on any zone of the lake, and which range the lake freely in pursuit of ciscoes and other forage fish, could be affected if declines in ciscoes occurred in the lake.

Declines in other forage fish, particularly troutperch and sticklebacks, could also affect annual production of walleye and pike, though not to the same extent as declines in ciscoes. Simultaneous declines in ciscoes, troutperch and sticklebacks would very likely have an adverse effect on productivity of walleye and pike.

15. Reduced summer flows could decrease losses of plankton from the lake and thus increase productivity. This could counteract to some extent other tendencies toward reduction in productivity. This effect could

also accelerate the process of eutrophication. However, such phenomena are difficult to quantify.

16. Spring spawning of gravel-spawners in Muskeg and Little Rivers may be affected by higher water levels, resulting in heavier sedimentation and less scour. Some presently marginal areas may become unsuitable for gravel spawners. A major reduction in gravel spawning areas by this mechanism is not anticipated, as spring flows should undergo velocity reductions of only 15 - 20% in most cases. Drowning out of the mouth of Little River may affect spring spawning in the area.

17. Increased overwinter water level fluctuations should cause greater exposure of beach spawning areas to freezing and desiccation. However, generally higher water levels should increase the vertical range of suitable areas available in the fall. This may offset to some extent the effects of greater drawdown. However, the lowest elevation of suitable substrate may rise with raised water levels. Prediction of the effect of greater drawdown on fall spawners is made difficult by the fact that no quantitative data on the depth distribution of spawning products of whitefish and ciscoes is available in the literature. At present it appears unlikely that the small amounts of additional drawdown proposed would cause total spawning failures, but they could conceivably increase the variation in year to year spawning success.

From the point of view of damage to fall spawning, there appears to be little difference between Scheme B and Scheme C. Scheme C could conceivably cause less damage than Scheme B, because minimum winter water levels would be higher, while the amount of overwinter water level fluctuation would be the same as for Scheme B.

18. Use of carry-over storage to generate additional power, when high spring runoffs are anticipated, could greatly increase damage to eggs of fall-spawners and to winter buds and tubers of rooted aquatic vegetation.

19. Restriction of flow and heavy siltation of Kakisa River during the second year of construction would be almost certain to cause heavy mortality of eggs and young-of-the-year of spring-spawning grayling, walleye, pike and white suckers. Mortality of adult stocks and bottom fauna would also be a definite possibility. Damage to subadult and adult stocks of resident fish would persist for a number of years, as would damage to the present invertebrate fauna. Although adult grayling migrate upstream to spawn, and thus probably do not form a resident population, there is evidence that subadult grayling form a segrated population, resident in Kakisa River. Therefore, damage to grayling, caused by flow restriction and turbidity, could adversely affect not only the young-of-the-year class but also a subadult grayling population up to 6 years old.

20. Under careful flow management, it is likely that the downstream fishery would eventually recover after the project is completed. Productivity of the fishery might be reduced somewhat, because of reduced summer outflow of plankton from the lake.

21. Local residents, whose economy is centered on fishing, hunting and trapping, would suffer some loss of hunting and trapping, and would likely suffer loss of enjoyment of their immediate environment. Because trapping activities are so wide-ranging, the hydro scheme would affect less than 20% of productive trapping areas. Loss of hunting could be a more serious consideration, since considerable hunting effort is expended in the immediate area of Kakisa Lake.

Damage to the fishery would not likely be felt at the present level of exploitation, but should be felt if the fishery were more intensively managed and exploited.

22. Aesthetics, wildlife and fisheries damage could adversely affect use of Kakisa Lake region by area residents and tourists.

23. Predictions of environmental effects have been based on the assumption that water levels can be controlled both during construction and after the project is completed. If full supply level cannot be controlled under all possible circumstances, damage to vegetation and wildlife could be more severe than indicated in this paper.

24. Table 29 summarizes probable magnitudes of environmental impacts of Scheme C. This assessment is based on the assumption that all feasible steps would be taken to avoid unnecessary environmental damage.

Magnitude of impact refers to the effect of development on the particular resource being considered, regardless of magnitude of that resource. Thus a serious impact on the resource of minor occurrence is rated as serious. A comment is made in such cases as to the magnitude or importance of the resource to put the rating given into proper perspective. It should be pointed out that moderate or even light impacts on the commercial fishery can be significant in terms of dollar value.

RECOMMENDATIONS

1. Scheme B is recommended over Scheme C on the basis that it would cause less damage to terrestrial vegetation, wildlife and aquatic vegetation. It should be noted, however, that fall-spawning conditions may be slightly better under Scheme C than under Scheme B.

2. An upper storage limit, which would not cause permanent damage to lakeshore and riparian tree communities, should be considered as a development alternative. Such a scheme would involve approximately 4 ft (1.22 m) of usable storage and would be less economical from the power production point of view. However, it would be more compatible with other uses presently being made of the lake. Such a scheme would be more aesthetically pleasing and would minimize damage to wildlife habitat.

A more careful evaluation of this scheme would necessitate a detailed vegetation and soils survey, involving precise levelling and mapping, and perhaps a more careful consideration of the requirements of fall spawners.

3. In general, the aesthetic, navigational and fishing drawbacks of leaving dead brush and timber standing in flooded areas seem to outweigh the biological advantages. It may be desirable, however, to leave aside small areas of standing dead timber for waterfowl nesting sites. In general, trees will have to be cut flush with the ground in flooded areas to prevent them from being hit by boats and motors, since the water in most flooded areas containing trees will be less than three feet deep.

4. Care should be taken to avoid excessive disturbance of plant cover and root systems of trees, especially in areas of organic peat soil, to minimize the rate of soil erosion and to minimize dislodgement of floating

peat debris. This can be best achieved by carrying out tree-clearing operations in winter, when the soil is frozen.

5. It is not desirable to cut trees above full supply level until it is certain that they are being killed by raised water table. It is not known how far back the effects of raised water table would extend. Trees that are killed could be removed by local people as the need arises. Such an approach would provide some degree of long-term employment and would be instructive in demonstrating the effect of raised water tables in northern Canadian environments, a subject about which little is known.

6. Measures should be taken to ensure that the design full supply level is not exceeded, either during construction or during operation of the reservoir, so that unnecessary damage to terrestrial habitats is avoided. This would imply a design provision for passage of larger than anticipated flows in the second year of construction, if it became evident that the lake was about to back up above design full supply level. It would also imply that design of spillway structures should be sufficiently conservative to ensure that flooding above full supply level was extremely rare and of very short duration.

7. Adequate downstream flows should be provided to allow continued success of the downstream fishery in Kakisa River. This would involve measures to protect eggs and fry as well as the adult resident and transient population. Gravel bars should not be exposed by prolonged shutdowns. Adequate flows should be provided to prevent rapid rise in temperatures and resultant temperature shock to all life stages of fish including, eggs and fry. Care should also be taken to prevent sudden release of cool water if downstream water were to become warmed during a power cutback. A temperature maximum for water downstream of the turbines should also be imposed.

Operating rules to prevent stranding and temperature shock should be established for the power plant. Flow minimums can be established experimentally by observation of flows necessary to cover gravel bars and riffles. Rules for maximum rate of change of temperature and maximum allowable temperatures can be established by observation of natural temperature phenomena in the unregulated river in years of normal flow. It may be useful to place a number of recording thermographs in various deep and shallow areas of Kakisa River in the near future, before the river is impounded.

8. A minimum safe winter flow should be established to cover cases of extended winter shutdowns. The primary considerations would be to prevent freezing of spawning gravels in the mouth of Kakisa River near Beaver Lake and to protect resident fish and invertebrate populations throughout the river. Winter flows occurring in a normal flow year, without regulation, would probably be a safe and conservative criterion for an operating rule for winter flows. A more accurate assessment of the situation might be obtainable from field observations and measurements.

9. Strict precautions against siltation of the river should be exercised during the first year of construction, to minimize undesirable environmental impacts.

The nature of construction in the second year (i.e.: drastic flow cutback, dumping of fill directly into the river, and excavation of riverbed material) should make it very difficult to entirely prevent damage to the downstream fisheries. However, some protective measures are possible to reduce the impact of the more damaging operations. For example, the building of the cofferdam could be scheduled for April. If the date of cofferdam construction were advanced, it might also be possible to carry out the more damaging phase of main dam construction, which involves dumping fill directly into the river, in late April and early May. In addition, excavation work in the outlet region could be carried out almost any time in late winter or early spring, since the outlet remains open year round. Scheduling of the more damaging construction procedures earlier in the season would cause the greatest siltation effects to occur before, instead of during the spring spawning season, as would happen under the existing construction schedule.

Another measure, that might be effective in combatting the adverse effects of siltation, would be to pass the largest feasible downstream flow during the second summer of construction. This is recommended because higher flows would dilute the silt load, prevent settlement of suspended particles, increase oxygen supply and reduce dangerous temperature fluctuations.

10. It would be advantageous to allow high flows as soon as the project is completed. This would flush accumulated sediments from the stream and would allow the stream system to return to its natural state as quickly as possible. It is possible that some bottom organisms, adapted to swift-flowing conditions, and much of the fish fauna might survive the severe conditions placed upon them during the summer period of heavy construction activity. A quick return to more normal conditions may improve the recovery chances of such survivors and hasten the overall recovery of the stream system.

11. Construction procedures to minimize siltation, erosion, dangerous flow cutbacks, and general environmental damage to both river and lake environments should be written into the contract specifications to minimize conflicts and confrontations during the actual construction period.

12. A qualified environmental inspector should be on site during construction to ensure that environmental stipulations in the construction contract are adhere to, and that minimum disturbance to the terrestrial, lacustrine and fluvial environments occurs. This inspector should report to an agency, independent of the principals involved in completion of the project. He should have "on the spot" authority to stop work if procedures contrary to contract environmental stipulations occur.

13. A study of possible changes in ice dynamics upstream and downstream of the dam should be carried out to clarify the implications of impacts related to ice phenomena. This study should include a statement on the possible extent of ice cover upstream and downstream of the dam, the possibility of ice blockages in the outlet area during late April, May and early June, and the probable magnitude of delay in breakup of the lake as the result of flow restrictions on the outlet river. A study to determine the probability of stratification in Kakisa River upstream of the proposed dam should also be undertaken.

14. Accurate predictions on changes in spawning areas in parts of streams affected by lake levels would require additional data on stream velocities, cross-sections, suspended particle loads, substrate composition and bed loads.

Prediction of possible upward shift in the silt-bottomed areas of the lake, which would affect the area available for fall spawners, would require extensive data on lake turbidity and patterns of settlement and resuspension.

Prediction of siltation rate in the stretch of Kakisa River upstream of the dam would also require rather comprehensive data on flow velocity and turbidity in the outlet.

All the above questions are of biological significance. However, they were beyond the scope of the present study.

The desirability of further work to obtain such information depends on the value placed on the biological resources affected by siltation phenomena. Therefore, if more reliable predictions of the effects of the project on spring and fall spawning and on faunal development upstream of the dam are required, flow-turbidity - sedimentation studies are recommended.

15. If greater certainty is required concerning the effects of winter drawdowns on fall spawning success, it is recommended that a diving study be undertaken. This appears to be the only feasible way of obtaining reliable information as to the depth distribution of spawning products and survival of eggs on various substrates.

16. A program of regular monitoring of Kakisa Lake and surroundings should be instituted in order that an adequate record of the variability of biological and physical parameters of the ecosystem can be obtained prior to impoundment. Such a program could include temperature, turbidity and sedimentation measurements, and the securing of water, plankton and bottom samples from fixed sampling stations. Stations could be set up in such a way that a sampling run could be accomplished in one day. It should be possible to hire a local person to carry out the sampling procedure on a regular basis (say twice a month in the ice-free period and once a month in the iced-over period).

It would also be advantageous to start systematically recording date of breakup on the lake and its inflowing and outflowing streams. Annual mapping of the maximum extent and stem density of rooted aquatics would also provide information which would be invaluable in follow-up assessments.

17. Environmental impact studies have little value if predictions made are not tested after the project is completed. A major goal of environmental impact studies should be to learn from mistakes, so that such mistakes can be avoided in future projects. Therefore, if the proposed project is carried out, post-impoundment monitoring, to check the validity of predictions made in the present study, is strongly recommended. Such phenomena as the effects of small water level fluctuations on terrestrial and aquatic vegetation and on spawning success of spring and fall-spawners are not well-documented for northern Canadian environments.

Since post-impoundment readjustment is a long-term process, a long-term, low-intensity monitoring program should give a greater information return per dollar than a high-intensity, short-term program. However, it should be drawn to the reader's attention that the small size of the hydro project could also make it an ideal pilot research project for both intensive and long-term study. Such intensive research has been carried out for several small lake reservoirs in Sweden and the results have been fruitful.

18. A follow-up economic assessment of the project also seems desirable. This point has been forcefully expounded by Day (1972) who critically examined the costs and economic benefits of three small water resource projects in Ontario, several years after completion. He found in all cases that predicted benefits had been greatly overstated and predicted costs had been greatly underrated, to the extent that highly favorable predicted benefit-cost ratios proved grossly inaccurate, and actual benefit-cost ratios were in fact considerably less than one.

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Table 1. Characteristics of inflowing and outflowing streams

River	Max. length (mi) influenced by hydro development	Max. area (mi^2) influenced by hydro development	Depth (m) of channel Aug. 15	Nature of substrate
Tathlina River	2.7	0.130	1.2	Rock and coarse gravel
Kakisa River	4.92	0.355	1.2	Sand and silt in outlet area; rock and gravel downstream
Muskeg River	6.7	0.355	1.5	Gravel and sand in channel; debris in slack water
Little River	2.7	0.027	2.1	Gravel and sand in channel; debris in slack water
Campsite Creek	0.6	0.008	1.2 (est.)	Rock and coarse gravel
River 1	1.9*	0.019	1.2	Debris
River 2	2.5*	0.071	3.1	Debris
River 3	1.4*	0.021	0.7	Debris
All streams	23.4	0.986		

*Includes only main stem of stream; excludes tributaries.

Table 2. Morphometric characteristics of Kakisa Lake*

Depth (m)	Area (sq mi)	% total of lake area	Cumulative %	Nature of substrate
0-1	3.4	2.7	2.7	Coarse rubble to coarse sand; woody organic debris bottom in west end
1-2	15.1	11.8	14.5	As above but with higher silt content in vegetated areas
2-3	13.0	10.2	24.7	As above with slight increase in silt content
3-4	43.6	34.1	58.8	Transition zone; silt with small amount of sand and rock
4-5	20.6	16.1	74.9	Medium silt
5-6	27.0	21.1	96.0	Fine silt
6+	5.3	4.1	100.0	Fine silt

Total area - 128 sq mi**
Lake volume - 4.86 x 10^{10} cu ft**
Length of shoreline - 62.5 mi**

Average depth 3.8 m (12.35 ft)**
Flushing period - 1.1 yrs**
Shore development 1.56**

*Soundings taken August 1972; lake level 725.9 ft above mean sea level.

**Data on areas and distances based on uncontrolled mosaic by Underwood McLellan and Associates Ltd.; approximate scale - 1 in = ½ mi.

Table 3. Important plant species in Kakisa Lake area

Genus	Species	Common name	Principal areas of occurrence
Potamogeton	*richardsonii*	Clasping leaf pondweed	Outlet area; mouths of minor inflowing rivers; east and west ends of lake
Potamogeton	*pectinatus*	Sago pondweed	Outlet area; mouths of minor inflowing streams; north shore; east and west ends of lake
Potamogeton	*gramineus*	Variable pondweed	North shore
Myriophylum	*exalbescens*	Water milfoil	Minor inflowing streams
Nuphar	*variegatum*	Yellow waterlily	Minor inflowing streams
Rannuculus	*aquatalis*	White water-crowfoot	Minor inflowing streams
Ceratophyllum	*demersum*	Coontail	Minor inflowing streams
Vallisneria	*americana*	Wild celery	Minor inflowing streams
Fontinalis	spp.	Moss	Minor inflowing streams
Scirpus	*validus*	Soft-stem bulrush	Principally in west end; pockets along north shore
Typha	*latitolia*	Cattail	Only near potholes to west of lake
Equisitum	*fluviatile*	Horsetail	Outlet area, banks of minor inflowing streams; west shore

Table 3 (continued)

Genus	Species	Common name	Principal areas of occurrence
Carex	spp.	Sedge	Banks of minor inflowing rivers; meadows west of lake
Salix	spp.	Willow	Banks of minor inflowing rivers; eastern and western shores; sedge meadows west of lake
Alnus	spp.	Alder	Exposed shores of lake; well up steep south shore
Populus	*tremuloides*	Trembling aspen	Banks of minor inflowing streams; narrow strip on north, east and west shores; Kakisa and Tathlina Rivers; extensive areas on escarpment south of lake
Betula	*papifera*	Paper birch	Mouth of Tathlina River
Picea	*glauca*	White spruce	Upper reaches of minor inflowing rivers; narrow strip along north and east shores; Kakisa and Tathlina River; extensive areas on escarpment south of lake
Picea	*mariana*	Black spruce	Main vegetation type in all flat areas away from lake or streams
Pinus	*banksiana*	Jackpine	Locally on ridges in east end; locally on escarpment south of lake

Table 4. Distribution, abundance and areal extent of rooted aquatic vegetation, August 1973

Location	Area of dense aquatic vegetation (sq mi)	Area of moderately dense aquatic vegetation (sq mi)	Area of sparse aquatic vegetation (sq mi)
Vicinity of outlet	1.3		
Mouth of Muskeg River	0.6		
East end of lake		4*	3.8*
West end of lake			
Inflowing rivers	0.4	5*	1.9*
All areas	2.3	9	5.7
% lake surface	1.8	7	4.5
Total area rooted aquatics - 17 sq mi		% lake surface - 13.3%	

*Combined area of moderately dense and sparse vegetation was measured; relative proportions of moderately dense and sparse vegetation were estimated.

Table 5. Elevation of bases of tree trunks closest to lake - north shore

Location	Elevation of bases of closest young tree (ft above MSL)	Elevation of bases of closest mature trees (ft above MSL)
Cutline 1 (see Fig 1)	726.9	730.0
Cutline 2	no young trees	729.5
Cutline 3	727.8	729.4

Table 6. Secchi disk readings - Kakisa Lake, 1972

Month	No. of readings	Minimum reading	Maximum reading	Average reading
June	26	0.5	4.1	2.3
July and August	23	0.1	2.6	1.6
September and October	20	0.2	1.6	0.9

Table 7. Secchi disk readings - inflowing and outflowing streams, 1972

Name of stream	Number of readings	No. of readings to bottom	Range of reading not to bottom
Tathlina River	8	0	0.10-0.37
Little River	1	0	2.0
Muskeg River	19	17	1.9 -2.3
Kakisa River	4	2	0.4 -1.1
River 1	3	3	n.a.*
River 2	2	2	n.a.
River 3	2	2	n.a.

*n.a. - not applicable

Table 8. Water chemistry of Kakisa Lake and associate streams, 1972.

Location and time of year	Total alkalinity (mg/l)	Ca hardness (mg/l)	Total hardness (mg/l)	Conductance (micromhos)	Phosphate (ortho) (mg/l)	Nitrate (mg/l)	Sulphate (mg/l)	Silica	Iron	Chloride	Color	Turbidity (J.T.U.)	Filtrable dissolved solids (mg/l)
Kakisa Lake (under ice)													
Range	95-	92-	144-	230-	0.05-	0.05-	4-	3.5-	0.05-	1.84	6	2-	-
May 8 (6 samples)	229	191	274	530	5.20	0.07	30	6.2	0.64	5.35	50	20	-
Average	139	126	187	346	0.93	0.06	22	4.3	0.22	2.78	24	7	-
Kakisa Lake (ice-free)													
Range, June to	87-	90-	128-	240-	0.05-	0.02-	35-	1.7-	0.06	0.35	18-	2-	108-
October (19 samples)	112	120	164	280	0.70	0.06	42	4.0	4.24	2.41	448	180	387
Average	100	100	144	256	0.10	0.03	37	2.9	0.63	1.22	77	21	192
Muskeg River													
April 16	224	152	256	480	0.05	0.07	-	10.0	0.18	10.63	-	-	-
April 17	196	-	-	420	0.05	0.04	-	8.0	0.36	7.09	-	-	-
Average	108	152	256	450	0.05	0.06	-	9.0	0.27	8.86	-	-	-
Muskeg River													
June 14	103	158	224	380	0.05	0.03	103	4.0	0.20	2.13	207	32	250
July 31	112	114	184	300	0.05	0.03	47	2.7	0.20	1.45	87	15	316
Average	108	136	204	340	0.05	0.03	75	3.4	0.20	1.79	147	24	283
Little River													
June 15	126	130	188	290	0.05	0.03	36	6.5	0.06	2.13	190	29	197
July 31	124	116	160	280	0.05	0.02	36	3.9	0.22	0.96	100	19	299
Average	125	123	174	285	0.05	0.03	36	5.2	0.14	1.55	145	24	248
Tathlina River													
June 14	86	100	128	230	0.75	0.02	42	3.3	4.15	1.45	38	175	279
Kakisa River													
May 16	126	117	180	310	0.05	0.04	40	3.6	0.12	1.21	34	5	182
June 11	96	88	144	270	0.05	0.04	41	2.5	0.14	0.96	42	5	125
Average	111	103	162	290	0.05	0.04	41	3.1	0.13	1.09	38	5	154
River 1	160	164	184	360	0.05	0.03	36	10.0	0.14	5.35	250	45	-
River 2	157	148	196	360	0.05	0.02	24	4.6	0.10	0.46	125	15	363
River 3													
June 23	122	138	240	380	0.06	0.05	72	9.0	0.18	0.96	384	41	292
August 1	118	128	184	310	0.05	0.03	46	6.0	0.11	0.46	130	18	387
Average	120	133	212	345	0.05	0.04	59	7.5	0.15	0.71	261	30	340

Table 9. Analysis of invertebrates from a typical vegetated littoral area (east end of lake). One dipnet sample in strip 0.45 m(1.5 ft) wide by 5 m (16.4 ft) long.

	No of organisms	Wt of organisms (g)	% of total number of organisms	% of total weight of organisms
Mayfly nymphs *	1069	2.4968	74.5	50.0
Caddisfly larvae	77	1.1622	5.37	23.3
Aquatic hemiptera	119	0.4435	8.3	8.9
Amphipods	38	0.2377	2.7	4.7
Beetle larvae and adults	17	0.1667	1.2	3.3
Snails and clams	29	0.1554	2.0	3.1
Ostracods	32	0.1397	2.2	2.8
Leeches	2	0.0652	0.1	1.3
Chironomid larvae	36	0.0450	2.5	0.9
Others	16	0.0836	1.1	1.7
TOTAL	1435	4.9958	100.0	100.0

* See Table 10 for systematic classification of organisms.

Table 10. Species list of benthic organisms - Kakisa Lake (large number of samples)

Common name	Class	Order	Family	Genus	Species
Mayflies	Insecta	Ephemeroptera	Ephemeridae	*Hexagenia*	
				Ephemera	
			Baetidae	*Ephemerella*	
				Caenis	
			Heptageniidae	*Stenonema*	
Midges		Diptera	Chironomidae	*Chironomus*	
				4 other genera	
Biting midges			Ceratopogonidae	*Bezzia*	
				Probezzia	
Caddisflies		Trichoptera	Limnephilidae	*Limnephilus*	
			Rhyacophilidae	*Rhyacophilus*	
			Helicopsychidae	*Helicopsyche*	
			Molannidae	*Molanna*	
			Hydroptilidae	*Oxythira*	
			Phryganidae		
Snails	Gastropoda	Ctenobranchiata	Valvatidae	*Valvata*	*lewisii*
				Valvata	*tricarinata*
			Amnicolidae	*Amnicola*	
		Pulmonata	Lymnacidae	*Lymnaea*	
Clams	Pelecypoda	Eulamellibranchia	Sphaeriidae	*Pisidium*	
				Sphaerium	
			Anodontinae	*Anodonta*	

Table 10 (continued)

Common name	Class	Order	Family	Genus	Species
Scuds, sideswimmers	Crustacea	Amphipoda	Gammaridae	*Gammarus*	*lacustris*
			Talitridae	*Hyalella*	*azteca*
			Haustoridae	*Pontoporeia*	*affinis*
Opossum shrimps		Mysidacea	Mysidaceae	*Mysis*	*relicta*
Leeches	Hirudinea	Arhynchobdellida	Hirudidae	*Macrobdella*	*decora*
			Erpobdellidae	*Dina*	
Aquatic earthworms	Oligochaeta	Plesiopora	Naididae (probable)		
Roundworms	Nematoda	Rhabdita	Heteroderidae	*Dolidorchus*	
Mites	Arachnoidea				
Bryozoans	Phylactolaemata	Plumatellina	Plumatellidae	*Plumatella*	*repens*
			Cristatellidae	*Cristatella*	*mucedo*

Total number of species - 35+

Table 11. Abundance of organisms in Kakisa Lake, 1972 (silt-bottomed areas)

Organism	No. organisms/metre^2		
	Early summer (28 Ekman samples)	Mid summer (29 Ekman samples)	Fall (31 Ekman samples)
Mayflies of genus *Hexagenia*	78 (6.8)*	142 (9.6)	275 (13.6)
Other mayflies	29 (2.5)	7 (0.5)	0
Chironomids	331 (29.0)	348 (23.5)	635 (31.5)
Amphipods	180 (15.7)	126 (8.5)	33 (1.6)
Snails	214 (18.7)	300 (20.3)	409 (20.3)
Clams	226 (19.8)	327 (22.1)	264 (13.1)
Nematodes	48 (4.2)	155 (10.5)	254 (12.6)
Oligochaetes	0	36 (2.4)	89 (4.4)
Mites	8 (0.7)	10 (0.7)	26 (1.3)
Other organisms	29 (2.5)	27 (1.8)	31 (1.5)
Total number of organisms	1143	1478	2016

*Percent of total number of organisms.

Table 12. Weight analysis of bottom fauna from silt-bottomed areas of Kakisa Lake

	Mid Summer	Fall	
	July 31 - Aug 11 (19 Ekman samples)	Sept 10 - Oct 6 (18 Ekman samples)	Oct 6 - 7 (10 Ekman samples)
Depth range (m)	2.8 - 5.5	2.2 - 3.8	5.1 - 6.0
% Mayflies*	32.0	60.3	34.8
% Chironomids	16.6	9.9	41.4
% Snails	18.6	13.7	12.8
% Clams	12.7	7.2	7.8
% Amphipods	10.9	2.0	nil
% Others	9.2	6.9	3.2
Avg. wet wt (g/m^2)	5.48	15.17	9.85
Estimated avg dry wt (kg/ha)	6.58	18.00	11.82

* percent of wet wt; total wet weights of samples include mollusc shells.

Table 13. Statistical comparisons of organisms/m^2 in shallow zones (3-4 m) versus deep zone (>5 m) Kakisa Lake, September and October, 1972.

	Mean organisms/m^2	95% confidence limits of mean	Significance of difference between means
Small *Hexagenia* nymphs A (shallow	240.7	98.6 - 277.5	$.20<p<.30$
B (deep)	130.0	43.5 - 176.0	
Large *Hexagenia* nymphs A	102.7	47.9 - 122.9	$p<.001$***
B	21.4	3.0 - 32.2	
All *Hexagenia* nymphs A	349.0	216.6 - 403.9	$.001<p<.01$**
B	184.5	78.7 - 223.3	
Small chironomid larvae A	588.1	265.4 - 694	$p=.01$**
B	188.4	83.5 - 228.7	
Large *Chironomus* larvae A	7.45	0 - 12.8	$p<<.001$***
B	136.4	37.2 - 172.6	
Snails A	484.8	360.2 - 551.1	$.01<p<.02$*
B	329.6	156.9 - 421.8	
Clams A	324.7	109.1 - 345	$p<.5$
B	199.8	114.2 - 242.8	
Amphipods A	55.9	6.5 - 66.4	$.001<p<.01$
B	0	-	

* significant ** highly significant *** very highly significant

Table 14. Species list of benthic organisms - slow-flowing rivers (casual collection)

Common name	Class	Order	Family	Genus	Species
Mayflies	Insecta	Emphemeraptera	Baetidae	*Ephemevella* *Caenis*	
Midges		Diptera	Chironimidae	*Chironomus* *Prodiamesa* Approx. 8 other species	
Biting midges		Diptera	Ceratopogonidae	*Bezzia* *Probezzia* *Palpomyia*	
Blackflies		Diptera	Simulidae	*Simulium*	4-5 species
Caddisflies		Trichoptera			
			Rhyacophilidae	*Ryacophilus*	
			Helicopsychidae	*Heliopsyche*	
			Molannidae	*Molanna*	
			Hydroptilidae	*Oxythyra*	
			Hydopsychidae	*Hydropsyche*	
			Phryganidae	*Phrygania*	
				Banksiola	*Agrynia*
				Ptilostomus	
			Limnephilidae	*Limnephilus*	
				Platycentropus	
Damselflies		Odonata (Suborder Zygoptera)	Coenagrionidae	*Ischnura*	

Table 14 (continued)

Common name	Class	Order	Family	Genus	Species
Dragonflies	Insecta	Odonata	Aeshnidae	*Aeschna*	
		(Suborder Anizoptera)		*Boyeria*	
			Libellulidae	*Libellula*	
				Macromia	
Beetles		Coleoptera	Amphizoidae	*Amphizoa*	
			Haliplidae	*Haliplus*	
			Dytiscidae	*Dytiscus*	2 species
				Hydvovatus	
				Ilybius	
			Gyrinidae	*Gyrinus*	
Water bugs		Hemiptera	Corrixidae		
			Notonectidae	*Notonecta*	
			Gerridae	*Gerris*	
Collembola		Collembola	Poduridae	*Podura*	*aquatica*
Snails	Gastropoda	Ctenobranchiata	Valvatidae	*Valvata*	*lewisii*
				Valvata	*tricarinata*
		Pulmonata	Planorbida	*Gyraulus*	*parvus*
				Gyraulus	*circumstriatus*
				Heliosoma	*anceps*
				Heliosoma	*trivolvus*
				Promenetus	*excuous*
			Lymnaeidae	*Limnaea*	*palustris*
				Limnaea	*stagnalis*
			Physidae	*Physa*	

Table 14 (continued)

Common name	Class	Order	Family	Genus	Species
Limpets	Gastropoda	Pulmonata	Ancylidae		
Clams	Pelecypoda		Sphaeriidae	*Pisidium* *Sphaerium* *Mucilium*	
			Anodontinae	*Anodonta*	
Scuds, Sideswimmers	Amphipoda	Amphipoda	Gammaridae	*Gammarus*	
			Talitidae	*Hyalella*	
Leeches	Hirudinea	Arhychobdellida	Hirudidae	*Macrobdella*	*decora*
			Erpobdellidae		
Aquatic earthworms	Oligochaeta	Plesiopora	Naididae	*Stylaria*	*fossularis*
Roundworms	Nematoda	Rhabdita	Heteroderidae	*Dolichodorus*	
Ostracods	Ostracoda			*Ilyoeypris*	
Bryozoans	Phylactolaemata	Plvmatellina	Plumatellidae	*Plumatella*	*repens*
			Cristatellidae	*Cristatella*	*mucedo*

Total number of species - 68+

Table 15. Plankton analysis, Kakisa Lake, 1972

	Late spring June 20 - 21 (3 vertical hauls)	Mid summer Aug. 2 (3 vertical hauls)	Fall Oct. 6 - 7 (3 vertical hauls)
Avg. distance per vertical haul (m)	5.9	5.5	5.2
Avg. dry wt. per vertical haul (mg)	40.5	13.5	25.9
Avg. dry wt. per unit area (kg/ha)	102.3	34.1	65.5
Dominant phytoplankters	diatoms	blue-greens	diatoms
Zooplankton (no. per 1)			
Limnocalanus macrurus	5.1	5.7	0.9
Cyclops	2.4	2.7	2.8
Unident. copepods	nil	nil	0.2
Diaphanosoma	nil	2.5	nil
Daphnia	0.1	5.9	0.2
Bosmina	0.6	0.3	0.1
Leptodora		present but missed by subsampling	
All zooplankters	8.2	17.1	4.2

Table 16. Spring spawning - Kakisa Lake, 1972

Date	Species	No. mature males	No. mature females	% males spawned	% females spawned
May 20	Walleye	23	3	4.4	0
	Pike	8	12	62.5	41.7
	Longnose sucker	4	1	0	0
	White sucker	9	7	0	0
May 21	Walleye	50	23	0	0
	Pike	12	10	83.4	100
	Longnose sucker	2	0	0	--
	White sucker	3	1	0	0
May 22	Walleye	72	5	25.0	100
	Pike	13	13	100	66.7
	Longnose sucker	0	0	--	--
	White sucker	0	0	--	--
May 23	Walleye	19	1	26.4	100
	Pike	7	4	100	100
	Longnose sucker	0	0	--	--
	White sucker	0	1	--	100
May 24	Walleye	40	11	42.5	72.8
	Pike	1	3	100	100
	Longnose sucker	0	0	--	--
	White sucker	0	2	--	0

Table 16 (continued)

Date	Species	No. mature males	No. mature females	% males spawned	% females spawned
May 25	Walleye	33	7	66.7	14.3
	Pike	0	0	--	--
	Longnose sucker	0	0	--	--
	White sucker	1	2	0	0
May 26	Walleye	25	2	100	100
	Pike	1	2	100	100
	Longnose sucker	0	0	--	--
	White sucker	0	0	--	--
May 27	Walleye	24	3	95.8	0
	Pike	0	0	--	--
	Longnose sucker	1	0	0	--
	White sucker	2	4	0	25.0
May 28	Walleye	26	1	92.3	0
	Pike	0	0	--	--
	Longnose sucker	0	0	--	--
	White sucker	0	1	--	100
May 29	Walleye	27	3	96.3	33.3
	Pike	0	0	--	--
	Longnose sucker	0	0	--	--
	White sucker	0	0	--	--

Table 16 (continued)

Date	Species	No. mature males	No. mature females	% males spawned	% females spawned
May 30	Walleye	18	2	100	50.0
	Pike	0	0	--	--
	Longnose sucker	0	0	--	--
	White sucker	2	1	50	100
June 4	Walleye	2	7	100	100
	Pike	1	12	100	100
	Longnose sucker	0	0	--	--
	White sucker	0	6	--	83.3
June 5	Walleye	4	13	100	100
	Pike	0	0	--	--
	Longnose sucker	0	0	--	--
	White sucker	3	0	100	--
June 6,7	Walleye	7	12	100	100
	Pike	0	2	--	100
	Longnose sucker	0	0	--	--
	White sucker	1	2	100	100
June 8	Walleye	3	14	100	100
	Pike	1	5	100	100
	Longnose sucker	0	0	--	--
	White sucker	0	1	--	100

Table 17 Spring spawning downstream of Lady Eveleyn Falls

	Grayling				Walleye				Pike			
Date	No. mature males	No. mature females	% males spawned	% females spawned	No. mature males	No. mature females	% males spawned	% females spawned	No. mature males	No. mature females	% males spawned	% females spawned
May 23									2	0	100	--
May 25									6	0	100	--
May 26					4	1	100	100	4	3	25	33.3
May 27	1				0	1	--	0	3	0	0	--
May 28									3	0	0	--
May 29									3	0	0	--
May 30									3	1	0	0
May 31	1								2	3	0	0
June 1	2	1	100	100					2	1	0	100
June 2									2	8	50	37.5
June 3	1	9	100	100	2	1	0	0	8	6	12.5	33.3
June 4									0	2	--	0
June 5					2	0	0	--	1	0	0	--
June 7					3	0	0	--				
June 8	2	2	100	100	2	1	--	100				
June 9					2	0	0	--	1	0	0	--
June 11	0	1	--	100								
June 14	1	0	100	--								
June 15									1	4	100	100

Note: Longnose sucker: May 27, 1 ripe male; June 3, 2 ripe females. June 6: heavy run of ripe longnose sucker at river ford.

Grayling: Large sports catches of near ripe grayling below highway bridge - May 17.

Table 18. Fall spawning - Kakisa Lake, 1972

Date	Location	Species	Mature males	Mature females	% males spawned	% females spawned
Sept. 17	Whitefish Bay	Whitefish	41	18	0	0
		Cisco	60	50	0	6
Sept. 18	Whitefish Bay	Whitefish	0	5	0	0
		Cisco	4	3	0	0
Sept. 19	Whitefish Bay	Whitefish	12	26	0	23
	Deep Bay	Whitefish	5	7	0	0
	Tathlina River	Whitefish	7	9	0	22
	Muskeg River	Whitefish	0	1	0	0
		Cisco	2	4	0	0
	All locations	Whitefish	24	43	0	19
		Cisco	2	4	0	0
Sept. 20	Whitefish Bay	Whitefish	22	24	9	67
		Cisco	26	13	0	0
	Deep Bay	Whitefish	11	9	9	56
	Tathlina River	Whitefish	4	16	75	25
	Muskeg River	Whitefish	0	0	0	0
	All locations	Whitefish	37	47	16	53
		Cisco	26	13	0	0

Table 19. Estimated degree of use of spawning areas, Kakisa Lake and associated streams

Species	Estimated degree of use									
	Kakisa River (below falls)	Kakisa River (above falls)	Muskeg River	Little River	Tathlina River	Campsite Creek	Rivers 1,2,3	S + E shores	N shores	W shores
Arctic grayling	C***									
Walleye	C**	C*	C***	*	*	**	*	*	*	
Pike	C**		***	**	**		***	*		**
Burbot					***			**		
White sucker		C***	**	***	***	**	*	*	C*	
Longnose sucker	C***		**	***	***	**	*	*	*	
Trout-perch		**	***	***	C***	**		**	**	
Spottail shiner		C**	***	***	***	**		**	**	
Lake chub			***	***	***			**	**	
Stickleback		***	***	***		***	*	*	*	***
Slimy sculpin	***				***			***	***	
Lake cisco					C***			C***	***	
Lake whitefish					C***			C***	***	
Round whitefish		***						***	***	

^{C}Spawning use confirmed by observations.

*Lightly used for spawning.

**Moderately used for spawning.

***Heavily used for spawning.

Table 20. Relationships between predator weight and preferred prey

Predator	Weight class (g)	Sample size*	Percent of predators feeding on**							
			Some invertebrates	Only invertebrates	Ciscoes	Trout-perch	Sticklebacks	White suckers	Walleye	Burbot
Walleye	0- 99	15	40	20	7	0	33	0	0	0
	100- 499	15	40	7	0	7	13	0	0	0
	500- 999	46	28	15	29	5	19	0	2	0
	1000-1499	7	0	0	43	0	43	0	14	0
	1500+	1	100	100	0	0	0	0	0	0
Pike	0- 99	4	75	50	0	25	0	0	0	0
	100- 499	13	46	38	0	46	0	8	0	0
	500- 999	22	18	14	50	9	9	5	5	0
	1000-1499	29	7	0	52	0	0	0	4	4
	1500+	21	5	5	81	14	14	0	5	5

*Includes only fish with food in stomachs.

**Sum of columns 2 to 8 generally less than 100% because of large number of fish containing unidentifiable fish remains.

Table 21. Stomach contents of miscellaneous fry and forage fish, 1972

Fish species	Food organism	% of stomachs of feeding fish containing organism	Total number of organisms in all stomachs	Estimated weight (g)	% wt. of food in all stomachs
Trout-perch	Mayfly larvae	67	2	.040	97.5
(adults)	Chiromomid larvae	33	1	.001	2.5
Gut empty 6					
Feeding 3					
Spottail shiners	Chironomid larvae	33	4	.004	5.8
(adults)	Other dipterans (adult)	33	4	.004	5.8
Gut empty 2	Other dipterans (larvae)	22	2	.002	2.9
Feeding 9	Caddisfly larvae	11	1	.010	14.5
	Stonefly larvae	11	1	.010	14.5
	Unidentified insects	11	4	.020	29.0
	Cladocerans	11	1	.0003	.4
	Fish eggs	11	19*	.019	27.6
Spottail shiners	Chironomid larvae	50	8	.008	29.5
(fry)	Cladocerans	100	63	.019	70.5
Gut empty 0					
Feeding 10					
Lake chub	Mesquito adults	33	1	.001	2.0
(adults)	Water bugs	67	5	.050	98.0
Gut empty 1					
Feeding 3					

Table 21 (continued)

Food species	Food organism	% of stomachs of feeding fish containing organism	Total number of organisms in all stomachs	Estimated weight (g)	% wt. of food in all stomachs
Sticklebacks	Cladocerans	50	50	.015	98.7
Gut empty 2	Copepods	50	2	.0002	1.3
Feeding 2					
Pike fry	Mayfly adults	22	3	.060	35.6
Gut empty 1	Chironomid larvae	11	1	.001	0.6
Feeding 9	Other dipterans (adult)	11	1	.001	0.6
	Copepods	89	55	.0055	3.3
	Ostracods	11	1	.001	0.6
	Burbot	11	1**	.100	59.3

*Assumed to be small trout-perch eggs approximately 1/10 weight of eggs of large fish.

**Very small burbot approximately size of a large mayfly nymph (100 g).

Table 22. Mean weights (g) of walleye, pike and lake whitefish in Kakisa Lake and in several other western Canadian lakes

Species	Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Age														
Wall-eye	Kakisa Lake, N.W.T.		45	76	113	286	416	471	555	750	807					
	Great Slave Lake,[1] N.W.T.					137	233	358	540	725	910					
	Lac la Ronge,[2] Sask.		83	171	284	415	591	765	1000	1180	1425	1730	2090	2640		
	Big Peter Pond,[3] Sask.					327		545								
	Cree Lake,[4] Sask.	91	227	364	591	865	1090	1545	2045	2820						
	Wollaston Lake,[4] Sask.	85	199	341	540	767	1020	1250	1480	1730	2200	2270				
Pike	Kakisa Lake, N.W.T.	212	469	668	750	897	1086	1839								
	Great Slave Lake,N.W.T				200			400	600	800	1000	1600	1900	2500	3200	
	Lac la Ronge, Sask.		318		1138		2140		3270		5050		6420		8190	
	Otter Lake,[5] Sask.						710						4550			
	Cree Lake, Sask.		23	50	95	182	273	455	590	772	1045	1360	1865	2270	2820	
	Wollaston Lake, Sask.			85	170	256	426	625	880	1140	1450	1950	2540	3270	4050	4820
Lake white-fish	Kakisa Lake, N.W.T.			105	272	393	590	696	706	932	1006	1074				
	Great Slave, N.W.T.								445		1025		1360		1710	
	Lac la Ronge, Sask.		114	156	242	341	440	568	696	865	1045	1228	1454	1729	2045	2455
	Big Peter Pond, Sask.					412		800								
	Cree Lake, Sask.		86	159	241	314	364	500	700	910	1180	1500	1910			
	Wollaston Lake, Sask.	43	85	170	256	284	455	570	740	965	1190	1450	1820	2140	2460	2860

[1] Rawson (1947)

[2] Rawson and Atton (1953)

[3] Rawson (1957)

[4] Rawson (1959)

[5] Rawson (1960b)

Table 23. Distribution of summer catch as to location and weight class

Lake zone	Number of overnight net sets	Number of fish caught																			
		Whitefish					White suckers					Walleye					Pike				
		0- 99 g	100- 499 g	500- 999 g	1000-1499 g	1500+ g	0- 99 g	100- 499 g	500- 999 g	1000-1499 g	1500+ g	0- 99 g	100- 499 g	500- 999 g	1000-1499 g	1500+ g	0- 99 g	100- 499 g	500- 999 g	1000-1499 g	1500+ g
East end in weeds	8	37	11	14	16	2	11	4	21	7	4	35	27	40	6		7	9	24	12	5
East end in open water	5		3	22	19			2	5				2	16	4				5	10	3
Central basin	4			2	1								1	8	4					5	3
North shore	5	1	4	4	1		11	2	10	6	2	23	8	22	3			2	1	2	5
West end in weeds	3	8	3	15	12	1					1	2		3			1			2	4
South shore	4	6	1	4	2					2			1	4	1	1			3	12	8
Tathlina River	1						6					1	3	4							1

Table 24. Biological and physical ranking of Kakisa Lake with northern Saskatchewan lakes, after Rawson (1960b, 1961)

	Mean depth	Mean summer temperature 0-10 m	Transparency (Secchi Disk)	Average bottom oxygen (July-August)	Total dissolved solids	Physical "score" of possible 70	Quantity of plankton	Weight of bottom organisms	Weight of fish per standard net	Biological "score" of possible 42
On Precambrian Shield										
Wollaston	3	1	3	1	2	10	1	5	4	10
Cree	5	4	1	3	1	14	2	1	6	9
Reindeer	4	3	2	6	3	18	3	2	5	10
Athabaska	1	2	5	2	4	14	6	4	3	13
Frobisher	12	9	14	7	5	47	7	3	2	12
Across margin of Shield										
Aminsk	7	5	7	12	6	37	4	9	1	14
Hunter Bay	2	6	4	5	7	24	5	6	8	17
La Ronge	8	8	6	10	11	43	8	7	12	27
On Glacial Drift, south of Precambrian										
Churchill	10	13	11	9	8	51	14	10	7	31
Ile a la Crosse	11	12	9	11	12	55	11	8	10	29
Little Peter Pond	13	11	12	8	10	54	13	13	11	37
Big Peter Pond	6	7	10	13	9	45	12	14	14	40
Waskesiu	9	10	8	14	13	54	10	12	9	31
Kakisa	14	14	13	4	14	59	8	7	13	28

Table 25. Weights of "standard gang" catches in 1968 F.R.B., Kakisa Lake study

Date	Weight of catch (Kg)						
	1½ in mesh 50 yd	2 in mesh 50 yd	3 in mesh 50 yd	4 in mesh 50 yd	5 in mesh 50 yd	5½ in mesh 50 yd	"Standard gang" 300 yd
August 13, 1968	0.73						
August 14, 1968	7.13						
August 15, 1968			35.78	33.01	17.48		
August 21, 1968	8.45	5.95	11.35	5.08	0.95		
August 22, 1968	4.18	10.72	21.21	16.75			
August 23, 1968		1.04	34.30	13.31		1.0441	
August 28, 1968				12.12	2.54		
Average	5.12	5.90	25.66	16.06	6.99	1.0441	60.77

$$\frac{\text{Average weight of "standard gang" catch}}{\text{Average weight of catch from } 1\tfrac{1}{2} \text{ and } 4 \text{ in meshes}} = 2.87$$

Table 26. Weight data for summer catches (July and August, 1972)

Lake zone	No. of overnight net sets	Range of weights of catch (Kg) 20 yds, 1½ in mesh; 20 yds, 4 in mesh	Weight of average catch (Kg) 20 yds, 1½ in mesh; 20 yds, 4 in mesh	Weight of equivalent "standard gang" catch (Kg) 50 yds, each of 1½, 2, 3, 4, 5½ in mesh
East end in weeds	7	5.05-20.18	10.85	77.8*
East end in open water	5	8.22-30.18	17.51	125.6
Central basin	4	2.01-10.62	7.34	52.6
North shore	5	1.54-18.57	12.55	90.0
West end in weeds	3	8.45-19.70	15.45	110.8
South shore	5	5.49-19.69	10.44	74.9
Average	29	1.54-30.18	12.21	87.6

*This figure arrived at by multiplying column to left by 7.175.

$$\text{Conversion factor} = \frac{\text{Weight average total catch (F.R.B.)}}{\text{Weight average catch from } 1\tfrac{1}{2} \text{ and 4 in mesh (F.R.B.)}} \times \frac{\text{Length F.R.B. (1968) nets}}{\text{Length 1972 study nets}}$$

$$= 2.87^{**} \times \frac{50 \text{ yds}}{20 \text{ yds}} = 7.175$$

**See Table

Table 27. Estimated distribution of nesting duck population in Kakisa Lake area

Location	Mi of Shoreline	Shoreline type	Dabblers** per mi	Divers** per mi	No of Dabblers	No of divers
West end						
Lakeshore	12.5	Tall shrub	6.9	1.9	86(28.7)***	24(8.0)
Riverbanks	11.6*	Tall shrub	6.9	1.9	80(26.7)	22(7.3)
East end						
Riverbanks	18.8	Deciduous	2.9	0.0	55(18.3)	0
Other Locations						
Rocky lakeshore	150.0	Rock	0.2	0.0	30(10.0)	0
Rocky riverbank	16.4	Rock	0.2	0.0	3(1.0)	0
All areas					254(84.7)	46(15.3)

* shoreline of rivers calculated at 2x length of main stem

** no. per mile in Peace-Athabasca Delta Project (1973)

*** percent of total no. of ducks

Table 28. Trapping records for Kakisa Village from records of game warden, D. Boxer, Hay River, N.W.T.

		Lynx	Beaver	Mink	Marten	Muskrat	Squirrel	Weasel	Bear	Wolf	Wolverine	Total
1969-70	A	41	109	36	5	81	63	30	3			368
	B	@ 14.53	@ 14.15	@ 12.66	@ 9.10	@ 0.81	@ 0.29	@ 0.50	@ 14.66			@ 7.67
	C	596.00	1582.50	456.00	45.50	66.00	18.60	15.13	44.00			2824.33
1970-71	A	64	86	67	10	16	264	88				595
	B	@ 17.61	@ 11.30	@ 9.90	@ 7.95	@ 0.68	@ 0.25	@ 0.60				@ 4.99
	C	1127.50	972.65	663.50	79.50	10.90	66.51	52.85				2973.81
1971-72	A	61	5*	51	11	2	4	11		2	1	148
	B	@ 23.26	@ 12.80	@ 15.29	@ 9.95	@ 1.00	@ 0.26	@ 0.40		@ 45.00	@ 30.00	@ 16.89
	C	1419.00	64.00	780.00	109.50	2.00	1.05	4.45		90.00	30.00	2500.00
1969-72	A	166	200	154	26	99	331	129	3	2	1	1111
	B	@ 18.93	@ 13.09	@ 12.33	@ 9.01	@ 0.79	@ 0.26	@ 0.56	@ 14.66	@ 45.00	@ 30.00	@ 7.46
	C	3142.50	2619.15	1899.50	234.50	78.90	86.16	72.43	44.00	90.00	30.00	8298.14

A - Number of pelts.

B - Average amount received per pelt.

C - Total amount received for pelts.

*1971-72 records for beaver do not include spring pelts, which normally account for the major portion of beaver pelts taken.

Table 29. Social and economic information related to land use by residents of Kakisa Village. Basic statistics are for summer of 1972. Estimates of fishing and hunting levels are for an average year. Fishing and trapping income and dollar value of locally-consumed animal resources are based on 1972 prices.

A. Native Population

I. Basic statistics

Number of residents		43
Number of inhabited cabins		8
Number of family units		7
Number of men under 65		15
Number of women under 65		8
Number of men over 65		4
Number of women over 65		4
Number of children		12
Number of dog teams	approx.	10
Number of sled doges	approx.	70
Number of small snow vehicles (Skidoos)		1
Number of canoes and boats	approx.	10
Number of outboard motors	approx.	10
Number of cars and trucks		0
Area of watershed utilized (sq mi)	approx.	3000

II. Gross annual earned income* from animal resources

i. Kakisa Lake (Kakisa watershed below mouth of Tathlina River

- fishing (approx. 32,000 lb @ $0.38/lb)	$12,160
- trapping (approx. 30% of annual harvest)	900
Total	$13,060

ii. Tathlina Lake (Kakisa watershed above mouth of Tathlina River

- fishing (approx. 20,000 lb @ $0.38/lb)	$ 7,600
- trapping (approx. 70% of annual harvest	2,100
Total	$ 9,700
Total of II	$22,760

Table 29 (continued)

III. Gross equivalent value** of animal resources consumed locally

i. Kakisa Lake

Dog food (56 dogs @ $90/dog/year)	$ 5,040
Moose meat (2 moose/year @ $300/carcass)	600
Fish for human consumption (4000 lb @ $1.00/lb)	4,000
Ducks (100 @ $1.00/bird)	100
Geese (25 @ $4.00/bird)	100
Hares (200 @ $2.00/hare)	400
Spruce grouse (50 @ $2.00/bird)	100
Total	$10,340

ii. Tathlina Lake

Dog food (14 dogs @ $90/dog/year)	$ 1,260
Moose meat (18 moose/year @ $300/carcass)	5,400
Fish for human consumption (1000 lb @ $1.00/lb)	1,000
Ducks (400 @ $1.00/bird)	400
Geese (100 @ $4.00/bird)	400
Hares (100 @ $2.00/hare)	200
Spruce grouse (25 @ $2.00/bird)	50
Total	$ 8,710
Total of III	$19,050
Total of II and III	$41,810

B. White Population

I. Basic statistics

Number of residents	5
Number of inhabited cabins	3
Number of family units	3
Number of men under 65	2
Number of women under 65	2
Number of men over 65	1
Number of women over 65	0
Number of children	0
Number of dog teams	0
Number of small snow vehicles (Skidoos)	2
Number of large enclosed snow vehicles (Bombardiers)	2
Number of boats	approx. 5
Number of motors	approx. 5
Number of cars and trucks	3

Table 29 (continued)

II. Gross annual earned income* from animal resources		
i. Kakisa Lake		
Fishing (9000 lb @ $0.38/lb)		$ 3,420
	Total	$ 3,420
ii. Tathlina Lake		
Fishing (50,000 lb @ $0.38/lb)		$19,000
	Total	$19,000
	Total of II	$22,420
III. Gross equivalent value of animal resources (consumed locally per year)		
Miscellaneous fish and game		$ 300
	Total of II and III	$22,720

*Net income substantially lower than gross income. Costs of transporting fish by surface from Kakisa Lake are 5¢ per lb. Air transportion costs from Tathlina Lake are 10¢ per lb for a full plane load and much higher for a partial plane load. In future, income from fishing should rise dramatically because of world shortages of animal protein. Pike are now (in 1973) economically exploitable. White and longnose suckers should become economically exploitable within one or two years. Fur prices have risen slightly since 1972 and the market appears strong into the indefinite future. Price rises, however, should not be as dramatic as for animal protein.

**Equivalent value calculated from purchase price (1972) of an equivalent protein supply from local retail stores. Quantities of animals consumed are subjective estimates based on observation of hunting and fishing activity over a seven-month period. It should be emphasized that estimates of the values of fish and wildlife consumed locally is only approximate, and is presented only for the general orientation of the reader. These estimates should not be construed as a detailed or accurate account of the value of these resources. It should be pointed out that the extremely rapid inflation in meat prices since 1972 is quickly pushing up the value of locally consumed animal resources of the area.

Table 30. Total annual lake level fluctuations under natural and regulated conditions for period of record (1964-71)

Time period	Total annual fluctuation (ft)		
	Scheme A (no regulation)	Scheme B (6 ft live storage)	Scheme C (8 ft live storage)
1964-65	4.3 (724.5)*	2.9 (726.3)	2.5 (728.7)
1965-66	4.0 (724.2)	3.2 (726.0)	3.2 (728.0)
1966-67	5.0 (723.8)	5.3 (724.0)	5.5 (725.7)
1967-68	5.5 (723.7)	4.9 (724.3)	4.9 (726.3)
1968-69	3.0 (724.1)	3.3 (725.3)	3.3 (727.2)
1969-70	4.2 (723.7)	5.2 (724.0)	6.2 (725.0)
1970-71	3.9 (723.6)	3.8 (724.1)	4.8 (724.1)
1971-72	3.7 (723.2)	3.9 (723.3)	3.9 (723.3)
Average	4.2 (723.9)	4.1 (724.7)	4.3 (726.1)
Mode	4.2 (723.8)	3.9 (724.3)	4.8 (726.3)

*Lowest water level, occurring just before spring thaw.

Table 31. Water level drop from time of maximum extent of rooted aquatics (Aug. 1) to time of spring low water level under natural and regulated conditions for period of record (1964-71)

Time period	Water level drop (ft)		
	Scheme A (no regulation)	Scheme B (6 ft live storage)	Scheme C (8 ft live storage)
1964-65	1.3 (724.5)*	1.4 (726.3)	1.0 (728.7)
1965-66	2.6 (724.2)	3.2 (726.0)	3.2 (728.0)
1966-67	2.4 (723.8)	4.8 (724.0)	5.2 (725.7)
1967-68	2.9 (723.7)	4.7 (724.3)	3.7 (726.3)
1968-69	2.8 (724.1)	2.7 (725.3)	2.3 (727.2)
1969-70	1.4 (723.7)	3.9 (724.0)	4.9 (725.0)
1970-71	3.1 (723.6)	3.4 (724.1)	3.7 (724.1)
1971-72	1.3 (723.2)	2.4 (723.3)	2.4 (723.3)
Average	2.3 (723.9)	3.3 (724.7)	3.3 (726.1)
	2.6 (723.8)	3.4 (724.3)	3.7 (726.3)

*Lowest water level, occurring just before spring thaw.

Table 32. Water level drop from time of fall spawning (Oct. 1) to time of spring low water level under natural and regulated conditions for period of record (1964-71)

Time period	Water level drop (ft)		
	Scheme A (no regulation)	Scheme B (6 ft live storage)	Scheme C (8 ft live storage)
1964-65	2.6 (724.5)*	2.7 (726.3)	2.2 (728.7)
1965-66	2.0 (724.2)	3.2 (726.0)	3.2 (728.0)
1966-67	1.8 (723.8)	4.0 (724.0)	4.1 (725.7)
1967-68	1.9 (723.7)	4.2 (724.3)	4.1 (726.3)
1968-69	2.3 (724.1)	3.3 (725.3)	3.3 (727.2)
1969-70	0.6 (723.7)	2.6 (724.0)	3.9 (725.0)
1970-71	2.4 (723.6)	2.7 (724.1)	3.1 (724.1)
1971-72	0.8 (723.2)	1.8 (723.3)	1.8 (723.3)
Average	1.8 (723.9)	3.1 (724.7)	3.2 (726.1)
	2.3 (723.8)	3.2 (724.3)	3.3 (726.3)

*Lowest water level, occuring just before spring thaw.

Table 33. Mean and median summer water levels under natural and regulated conditions for period of record (1964-71)

Date		Scheme A (no regulation)	Scheme B (6 ft live storage)	Scheme C (8 ft live storage)
June 1	A	727.9	728.5	730.0
	B		(0.6)	(2.1)
	C	728.2	729.2	731.2
	D		(1.0)	(3.0)
July 1	A	726.6	728.3	729.8
	B		(1.7)	(3.2)
	C	726.9	728.8	730.8
	D		(1.7)	(3.9)
August 1	A	726.0	728.1	729.5
	B		(2.1)	(3.5)
	C	726.4	728.0	729.9
	D		(1.6)	(3.5)
September 1	A	725.8	727.8	29.3
	B		(2.0)	(3.5)
	C	726.0	728.2	30.0
	D		(2.2)	(4.0)

A - Mean water level (ft above M.S.L.)
B - Increase in depth over unregulated case
C - Median water level (ft above M.S.L.)
D - Increase over unregulated case

Table 34. Summer water levels under natural and regulated conditions for the year 1965

Time period	Water level (ft above mean sea level)		
	Scheme A (no regulation)	Scheme B (6 ft live storage)	Scheme C (8 ft live storage)
June 1, 1965	728.2	729.2 (1.0)*	731.2 (3.0)
July 1, 1965	727.8	729.2 (1.4)	731.2 (3.4)
August 1, 1965	726.8	729.2 (2.4)	731.2 (4.4)
September 1, 1965	726.4	729.2 (2.8)	731.2 (4.8)

*Increase in water level over unregulated case.

Table 35. Areas affected by raised water levels (worst case: Scheme C)

Location	Area (sq mi) between normal water level and elevation 732	Area (sq mi) between elevation 732 and elevation 734	Total area (sq mi) affected by scheme
East shore	2.70	1.71	4.41
Mouth Tathlina River	0.21	0.04	0.25
South shore	0.15	0.05	0.20
North shore	0.79	0.32	1.11
West shore	4.93	2.09	7.02
All areas	8.78	4.21	12.99

Table 36. Areas between depth contours under natural and regulated conditions for August 1 median water levels of period of record (1964-71)

Zone	Contour interval (m)	Area between contours (sq mi)		
		Scheme A (Median water level 726.4 ft above M.S.L.)	Scheme B (Median water level 728.0 ft above M.S.L.)	Scheme C (Median water level 729.9 ft above M.S.L.)
Littoral	0-1	2.8	2.3 (82)*	4.7 (168)
	1-2	13.7	8.9 (65)	2.9 (21)
	2-3	13.3	14.4 (107)	12.6 (95)
Sub-littoral	3-4	39.0	24.2 (62)	13.5 (35)
	4-5	24.1	35.3 (147)	37.2 (154)
	5-6	26.0	23.3 (90)	25.5 (98)
	6-7	9.4	22.5 (242)	25.7 (274)
	7-8			11.0
	0-8	128.3	130.9 (103)	133.1 (104)

*Percent of Scheme A area.

Table 37. Areas between depth contours under natural and regulated conditions for August 1 water levels of 1965

Zone	Contour interval (m)	Area between contours (sq mi)		
		Scheme A (Water level 726.8 ft above M.S.L.)	Scheme B (Water level 729.2 ft above M.S.L.)	Scheme C (Water level 731.2 ft above M.S.L.)
Littoral	0-1	2.8	4.3 (154)	5.3 (189)
	1-2	13.0	3.4 (26)	2.3 (18)
	2-3	13.6	15.1 (111)	12.1 (89)
Sub-littoral	3-4	36.4	13.0 (36)	13.9 (38)
	4-5	26.2	43.6 (167)	30.6 (117)
	5-6	25.4	20.6 (81)	30.4 (120)
	6-7	11.9	27.0 (227)	24.3 (204)
	7-8		5.3	16.8
	0-8	129.3	132.3 (102)	135.7 (105)

Table 38. Area of zones suitable for aquatic vegetation in the east end of the lake under natural and regulated conditions

Depth zone (m)	Area of rooted aquatic vegetation (sq mi)		
	Scheme A (no regulation)	Scheme B (6 ft live storage)	Scheme C (8 ft live storage)
1-2	7.5*	8.5 (113)**	2.5 (33)
2-3	13.0	8.0 (62)	6.5 (50)

*Areas estimated to nearest half square mile.

**Percent of Scheme A area.

Table 39. Summary of Environmental Impacts

L = Light impact
M = Moderate impact
S = Severe impact
LM = Light to Moderate impact
MS = Moderate to Severe impact
? = Impact unknown
P = Positive effect
O = Neutral effect

Environmental Aspects under Consideration	Cause of Impact				Magnitude of Impact			Comments
	Construction Activity	Raised Water Levels	Winter Drawdown	Flow Regulation	Biological Impact	Impact on Aesthetics and Recreation	Impact on Local Residents	
Terrestrial Vegetation								
Willow Damage								
West End		X			S	S	S	
East End		X			S	S	S	Virtually all available wildlife habitat; also aesthetic consideration
Aspen Damage								
West End		X			S	S	S	
East End		X			S	S	S	
North Shore		X			L	S	L	
Spruce Damage								Primarily an aesthetic consideration
North Shore		X			L	S	L	
Aquatic Vegetation								
Reduction Lake Aquatics								Reduces lake production; reduces food and habitat for sub-adult and forage fish; depends on magnitude of storage and amount of drawdown
West End		X	X		M	L	MS	
East End		X	X		MS	L	MS	
Reduction River Aquatics		X			M	LM	MS	
Ice								
Delay of Lake Breakup				X	M	M	MS	Affects lake productivity and human activity.
Ice Jamming Outlet				X	MS	M	MS	Affects waterfowl and human activity.
Water Temperature								
Less Daily Temperature Fluctuation in Lake		X			P	O	P	
Slower Freezing of Lake		X			P	O	P	
Slower Spring Warming of Kakisa River				X	M	LM	O	Lowers annual production.
Greater Temperature Fluctuation of of Kakisa River	X			X	L	L	O	Provided adequate summer flows.
Erosion Turbidity Sedimentation								
Shoreline Erosion		X	X		LM	M	LM	
Long Term Decrease in Turbidity		X			P	P	P	May increase phytoplankton slightly.
Increased Sedimentation of Lake		X		X	?	?	?	Could increase annual production, but could hasten eutrophication.
Siltation of River Spawning Gravels		X			M	O	M	Effect proportional to silt load of stream.
Siltation of Fall-Spawning Areas		X			M	O	MS	
Siltation of Kakisa River Upstream of Dam		X			?	?	?	Faunal shift; possible increased production; possible insect swarms.
Siltation of Kakisa River Downstream of Dam	X				S	S	M	Short-term effect provided after construction to remove silt accumulation.

Table 29. (Continued)

Environmental Aspect under Consideration	Cause of Impact: Construction Activity	Cause of Impact: Raised Water Levels	Cause of Impact: Winter Drawdown	Cause of Impact: Flow Regulation	Magnitude of Impact: Biological Impact	Magnitude of Impact: Impact on Aesthetics and Recreation	Magnitude of Impact: Impact on Local Residents	Comments
Other Physical-Chemical								
Dissolved Oxygen Depletion		X			L	O	L	Highly localized in shallows.
Increased Color		X			L	O	L	
Release of Nutrients		X			?	?	?	Phosphates could increase, could increase annual production but could hasten eutrophication.
Increased Nutrient Retention		X			?	?	?	
pH Drops		X			L	O	L	Highly localized in shallows.
Bottom Organisms								
Rocky Littoral of Lake		X	X		L	O	L	Production already low.
Vegetated Littoral of Lake		X	X		MS	O	MS	Because of reduction in rooted aquatics.
Silt-Bottomed Areas of Lake		X			P	O	P	Because of increased plankton retention.
Slow-Flowing Streams		X			M	O	M	Because of reduction of rooted aquatics.
Tathina River (near Lake)		X			M	O	M	Production only moderate.
Plankton								
Initial Flush		X		X	P	O	P	Plankton may increase but eutrophication may be hastened; effect depends on whether lake is nutrient-limited.
Long-Term Increase		X		X	?	?	?	
Possibility of Blooms		X		X	M	M	M	
Increased Plankton Retention in Lake				X	?	?	?	
Fisheries (Lake)								
Walleye								
Spawning		X			L	L	L	Depends on silt load in spawning streams.
Food Chains		X	X		?	L	?	Depends on impact on lake cisco
Habitat		X			L	L	L	
Pike								
Spawning		X	X		LM	L	L	Life cycle strongly dependent on aquatic vegetation.
Food Chains		X	X		MS	L	M	
Habitat		X	X		MS	L	M	
White and Longnose Suckers								
Spawning		X			L	O	L	
Food Chains		X	X		M	O	M	
Habitat		X			L	O	L	
Lake and Round Whitefish								
Spawning		X	X		?	O	?	Difficult to predict; see main discussion.
Food Chains		X	X		M	O	M	
Habitat		X			L	O	L	
Cisco								
Spawning		X	X		?	O	?	Difficult to predict; see main discussion.
Food Chains		X		X	P	O	P	
Habitat					O	O	O	

Table 39. (Continued)

Environmental Aspect under Consideration	Cause of Impact: Construction Activity	Cause of Impact: Raised Water Levels	Cause of Impact: Winter Drawdown	Cause of Impact: Flow Regulation	Magnitude of Impact: Biological Impact	Magnitude of Impact: Impact on Aesthetics and Recreation	Magnitude of Impact: Impact on Local Residents	Comments
Fisheries (Lake) - (Cont'd)								
Sticklebacks								
Spawning		X	X		LM	O	L	Life cycle strongly dependent on aquatic vegetation.
Food Chains		X	X		MS	O	M	
Habitat		X	X		MS	L	M	
Other Forage Fish								
Spawning		X			L	O	L	
Food Chains		X	X		M	O	M	Aquatic vegetation contributes to productivity.
Habitat		X	X		L	O	L	
Physical - Chemical (Downstream)								
Delay in Spring Warmup				X	M	M	O	
Temperature Fluctuation during Shutdowns				X	L	L	O	Can be controlled by good plant management.
Turbidity and Sedimentation (Short-Term)	X				S	MS	O	May be lessened by special construction procedures.
Bottom Organisms (Kakisa River)								
Changes in Faunal Composition (Upstream of Dam)		X			?	?	?	Major faunal shift
Changes in Productivity (Upstream of Dam)		X		X	?	?	?	Possible increase in production; possible insect swarms.
Changes in Faunal Composition (Downstream of Dam)	X	X		X	M	M	O	Caused by slight environmental shift.
Changes in Productivity (Downstream of Dam)		X		X	M	M	O	Caused by greater retention of organic material in lake and upper river system.
Downstream Fishery (Short-term)								
Grayling								
Spawning	X			X	S	MS	L	Probably species most sensitive to siltation.
Food Chains	X			X	S	MS	L	Feeds on invertebrates affected by siltation.
Habitat	X			X	S	MS	L	Generally avoids muddy rivers.
Walleye								
Spawning	X			X	MS	MS	L	Probably slightly more tolerant of silty conditions. Piscivorous and therefore only secondarily affected by short-term changes in bottom fauna.
Food Chains	X			X	M	MS	L	
Habitat	X			X	MS	MS	L	
Pike								
Spawning	X			X	MS	MS	L	
Food Chains	X			X	M	MS	L	
Habitat	X			X	MS	MS	L	
Longnose Suckers								
Spawning	X			X	MS	L	L	
Food Chain	X			X	L	L	L	Can utilize invertebrates with high silt-tolerance.
Habitat	X			X	LM	L	L	Adults probably transient to stream.

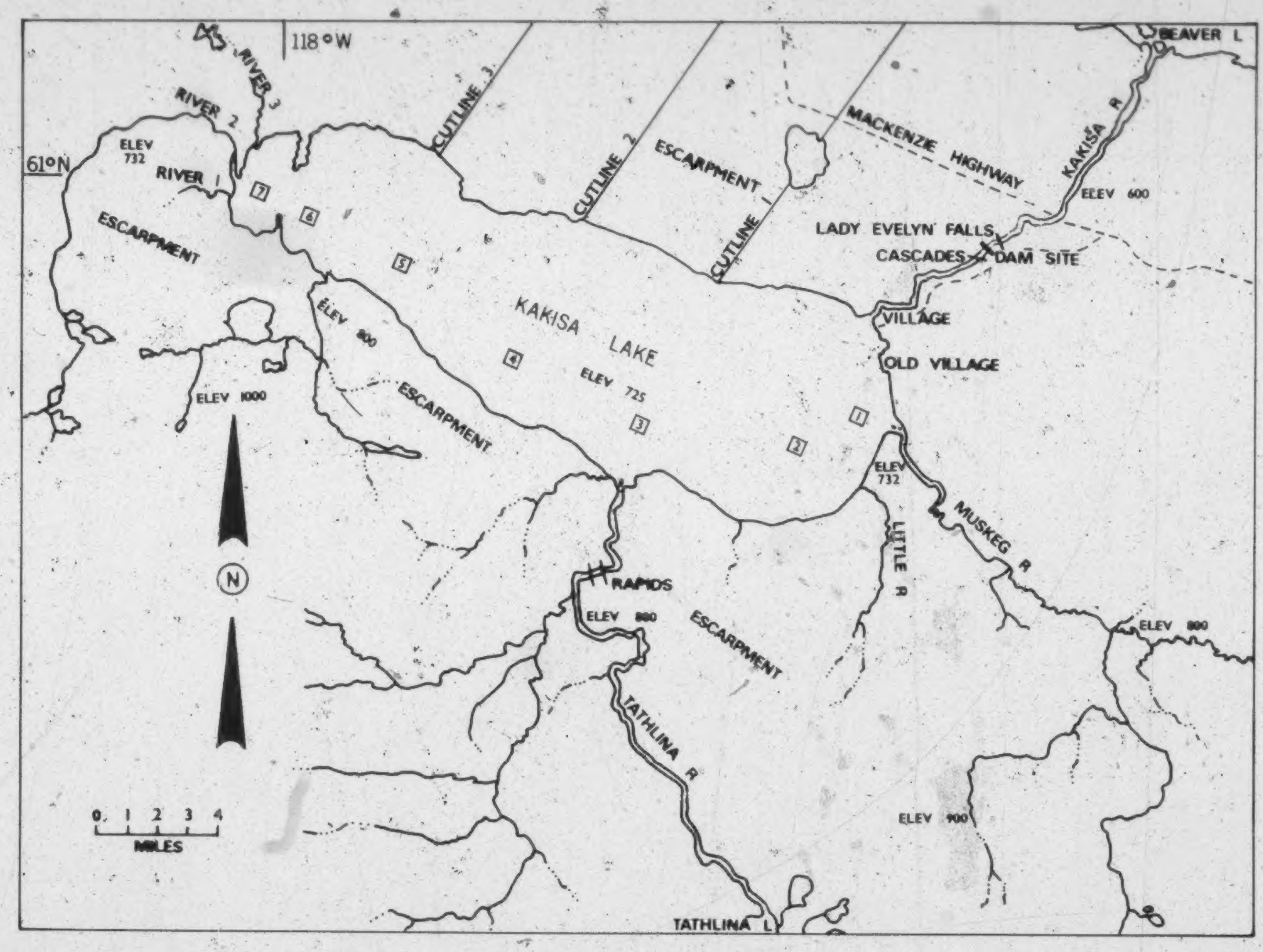
Table 39. (Continued)

Environmental Aspect under Consideration	Cause of Impact				Magnitude of Impact			Comments
	Construction Activity	Raised Water Levels	Winter Drawdown	Flow Regulation	Biological Impact	Impact on Aesthetics and Recreation	Impact on Local Residents	
Downstream Fishery (Short-term) (Cont'd)								
Lake Whitefish								
Spawning	X			X	S	O	S	Spawns in river mouth but river probably not a major habitat. Heavily fished by local residents.
Food Chains	X			X	L	O	O	
Habitat	X			X	L	O	O	
Downstream Fishery (Long-term)								
Grayling								
Spawning	X			X	LM	LM	O	
Food Chains	X			X	LM	LM	O	
Habitat	X			X	LM	LM	O	
Walleye								In general it should be possible to maintain present species composition if very careful consideration is given to providing continuous and adequate downstream flows. Productivity of fishery may be somewhat reduced.
Spawning	X			X	L	L	O	
Food Chains	X			X	M	L	O	
Habitat	X			X	L	L	O	
Pike								
Spawning	X			X	L	L	O	
Food Chains	X			X	M	L	O	
Habitat	X			X	L	L	O	
Longnose Suckers								
Spawning	X			X	L	O	O	
Food Chains	X			X	M	O	O	
Habitat	X			X	L	O	O	
Lake Whitefish								
Spawning	X			X	L	O	L	
Food Chains					O	O	O	
Habitat					O	O	O	
Waterfowl								
Spring								
Dabbling Ducks		X	X	X	S	MS	S	Approximately 500 ducks at any one time.
Diving Ducks		X	X	X	M	M	L	
Geese		X		X	L	L	L	Very few spring geese.
Swans		X	X	X	L	L	L	Very few spring swans.
Shorebirds		X	X	X	M	M	O	Probable maximum 500 - 1000.
Summer								
Dabbling Ducks		X	X		S	S	M	Estimated 300 nesting pairs, mostly in west end.
Diving Ducks		X	X		MS	M	L	
Geese					O	O	O	No nesting population.
Swans					O	O	O	No nesting population.
Shorebirds		X	X		M	M	O	Common
Fall								
Dabbling Ducks		X	X		LM	L	L	Probable maximum less than 2,000.
Diving Ducks		X	X		L	L	L	
Geese		X			S	S	MS	Maximum 100 sighted at one time.
Swans		X	X		LM	M	O	Maximum 200 sighted at one time.
Shorebirds					O	O	O	Not common in fall.

Table 39. (Continued)

Environmental Aspects under Consideration	Cause of Impact				Magnitude of Impact			Comments
	Construction Activity	Raised Water Levels	Winter Drawdown	Flow Regulation	Biological Impact	Impact on Aesthetics and Recreation	Impact on Local Residents	
Eagles and Ospreys								
Damage to Nesting Trees					?	?	O	Effects difficult to predict. Approx. 5 prs. eagles and 3 prs. ospreys.
Changes in Fish Distribution					L	O	O	
Furbearers								
Beavers		X	X		S	S	M	10 houses observed; carrying capacity likely less than 25 prs.
Muskrats		X	X		S	M	L	Scattered small population estimated less than 30 breeding pairs.
Snowshoe Hares		X			S	M	LM	
Lynx		X			MS	M	MS	Areas affected optimal habitat. Carrying capacity unknown.
Red Squirrels		X			S	M	L	
Marten		X			M	M	M	
Mink		X			M	M	MS	
Big Game								
Moose		X	X	X	S	S	S	Estimated population 14; estimated carrying capacity 98.
Bears		X			LM	M	O	Areas affected excellent habitat; carrying capacity unknown.
Wolves		X			LM	M	O	
Aesthetic and Recreational Values								
Plant Communities	X	X	X	X	S	S	S	40 miles shoreline, 20 miles of riverbanks.
Geomorphological Features	X	X			O	S	L	Cascades above fall a major loss.
Fish and Wildlife	X	X	X	X	MS	S	S	
Wilderness Value	X	X	X	X	O	S	S	
Improved Access to Lake		X			O	P	P	
Improved Access to Tathlina R. Rapids		X			O	P	P	
Human Ecology (Local Residents)								
Ice Impeding Boat Use				X	O	O	MS	Requires further theoretical calculations.
Damage to Commercial Fishery		X	X		LM	L	M	Slight damage has large dollar value.
Damage to Hunting		X	X		S	S	S	Area heavily hunted.
Damage to Trapping		X	X		S	S	M	Areas affected contribute less than 20% of total pelts taken.
Debris Interference with Fishing and Navigation		X			O	M	M	
Loss of Enjoyment of Environment	X	X	X	X			S	
Disruption of Lifestyle	X	X	X	X			S	
Improved Access to Lake		X				P	P	Also benefits visitors.

Figure 1. Kakisa Lake study area. Coordinates are given at lower left. Station numbers indicate locations of winter sampling stations. Major streams and landmarks are labelled. Spot elevations (feet above Mean Sea Level) are given.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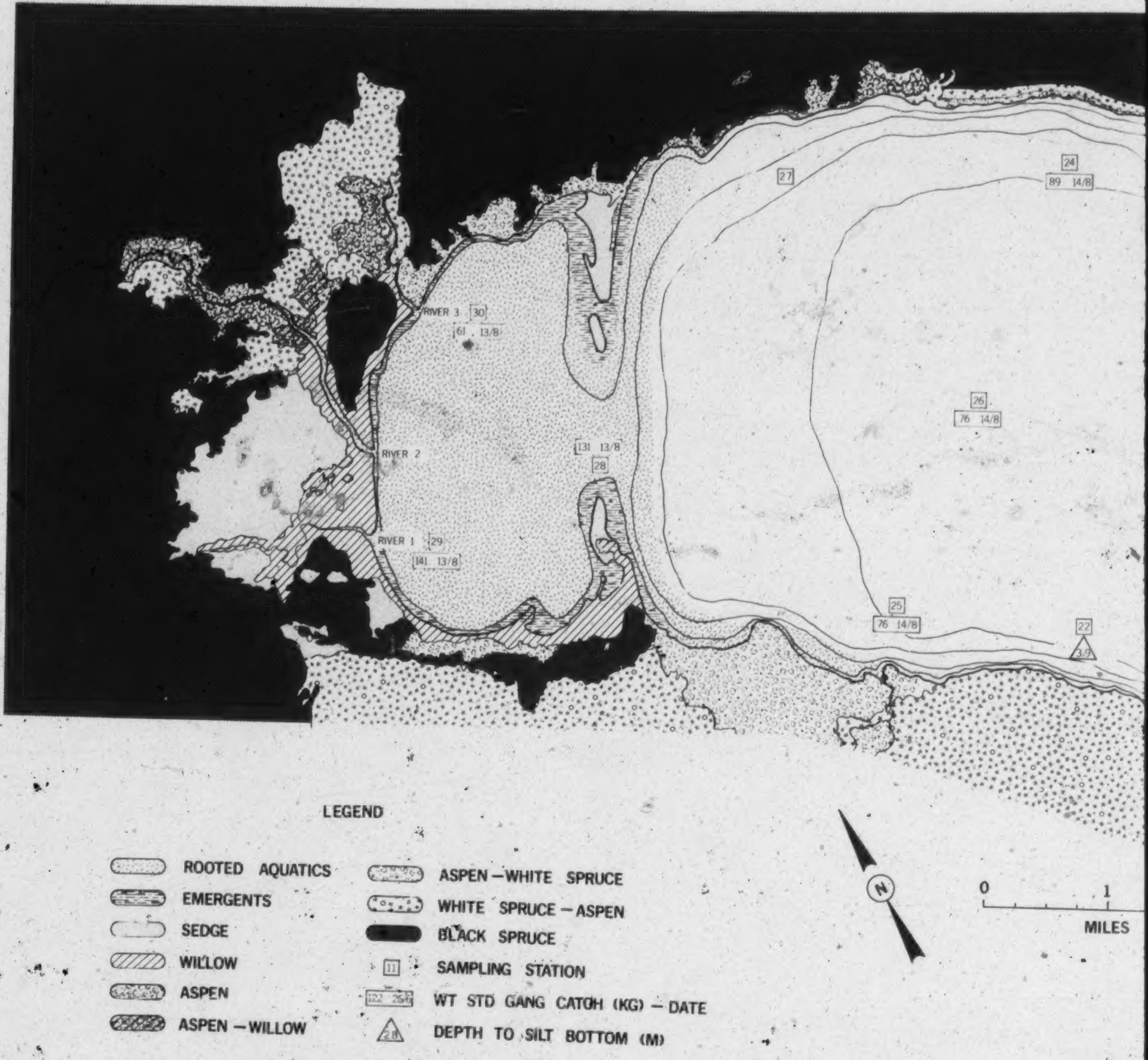
61°N
BEAVER L
KAKISA R
ELEV 600
MACKENZIE HIGHWAY
CUTLINE 1
CUTLINE 2
CUTLINE 3
ESCARPMENT
LADY EVELYN FALLS
CASCADES
DAM SITE
VILLAGE
OLD VILLAGE
RIVER 1
RIVER 2
RIVER 3
ELEV 732
ESCARPMENT
1
2
3
4
5
6
7
KAKISA LAKE
ELEV 725
ELEV 800
ESCARPMENT
ELEV 1000
N
ELEV 732
MUSKEG R
LITTLE R
RAPIDS
ELEV 800
ESCARPMENT
TATHLINA R
TATHLINA L
ELEV 800
ELEV 900
0 1 2 3 4
MILES

Figure 2. Environmental map of Kakisa Lake area. Soundings taken in mid-August, 1972, when water level was approximately 726 feet above Mean Sea Level. Map shows network of 30 summer lake sampling stations which should not be confused with seven winter sampling stations shown in Figure 1. Inflowing rivers were also sampled near mouths but stations are not shown on map. Station 3 was the most frequently sampled station. Only summer fishing locations used to calculate average "standard gang catch" are shown. Depths to silt bottom were measured in late September and early October when water level was approximately 725 feet above Mean Sea Level.

1 of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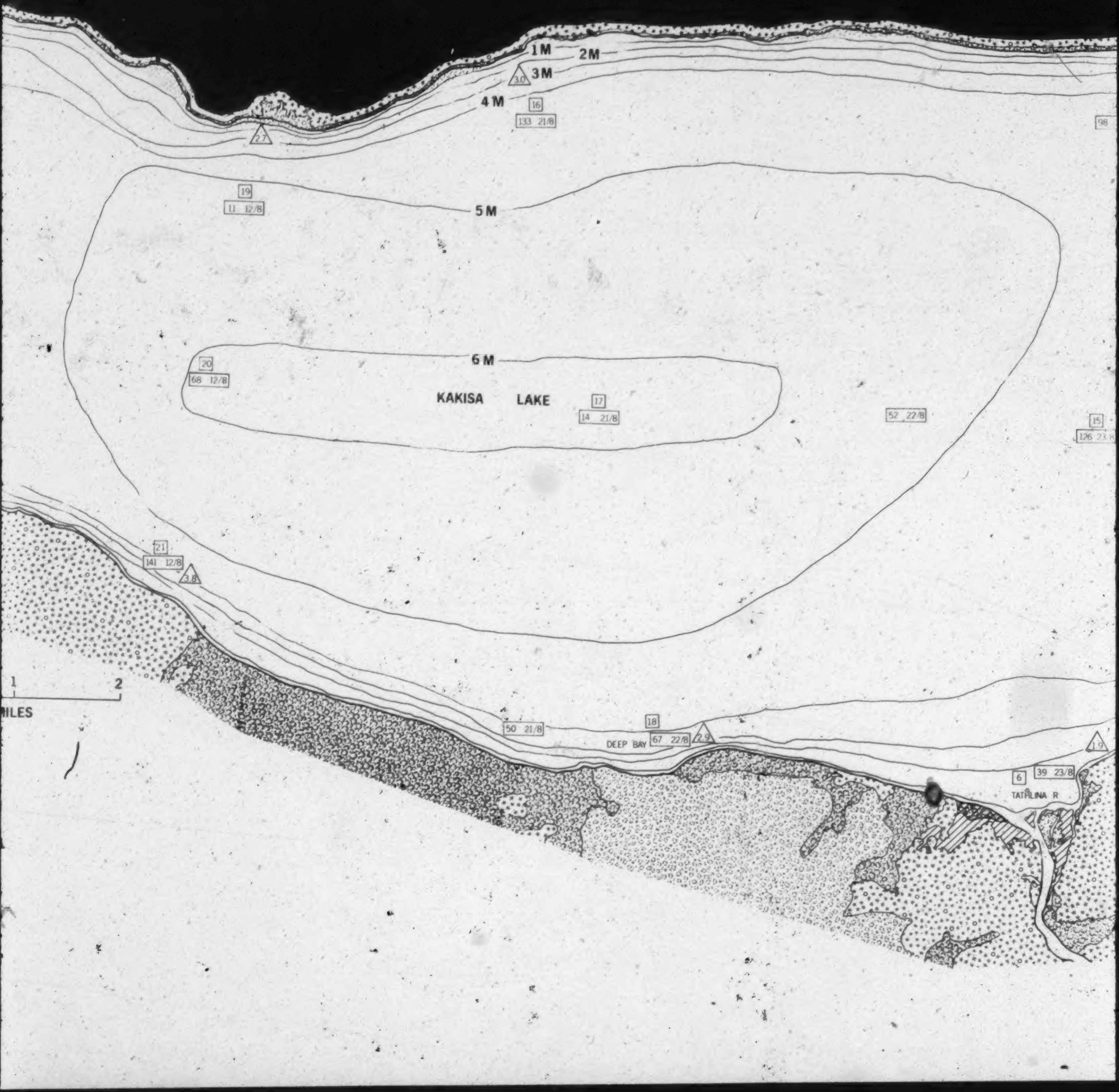
30
61 13/8
RIVER 2
131 13/8
28
RIVER 1
29
141 13/8
27
24
89 14/8
26
76 14/8
25
76 14/8
22
3.9
LEGEND
ROOTED AQUATICS
EMERGENTS
SEDGE
WILLOW
ASPEN
ASPEN — WILLOW
ASPEN — WHITE SPRUCE
WHITE SPRUCE — ASPEN
BLACK SPRUCE
11 SAMPLING STATION
122 26/8 WT STD GANG CATCH (KG) — DATE
2.8 DEPTH TO SILT BOTTOM (M)
N
0
1
MILES

FIG 2 ENVIRONMENTAL MAP OF KAKISA LAKE AREA

2 of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3M
4M
5M
6M
3.0
16
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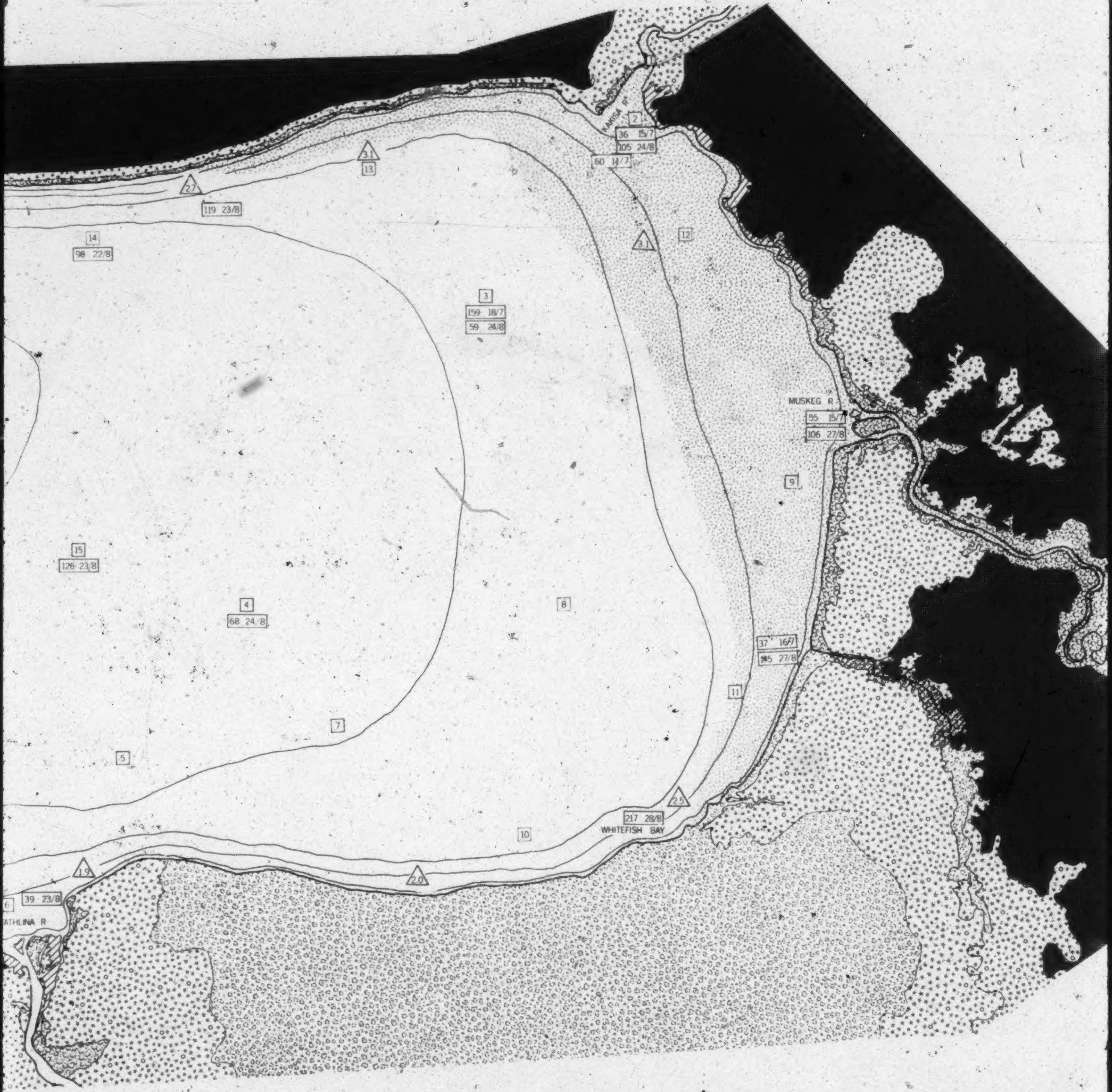
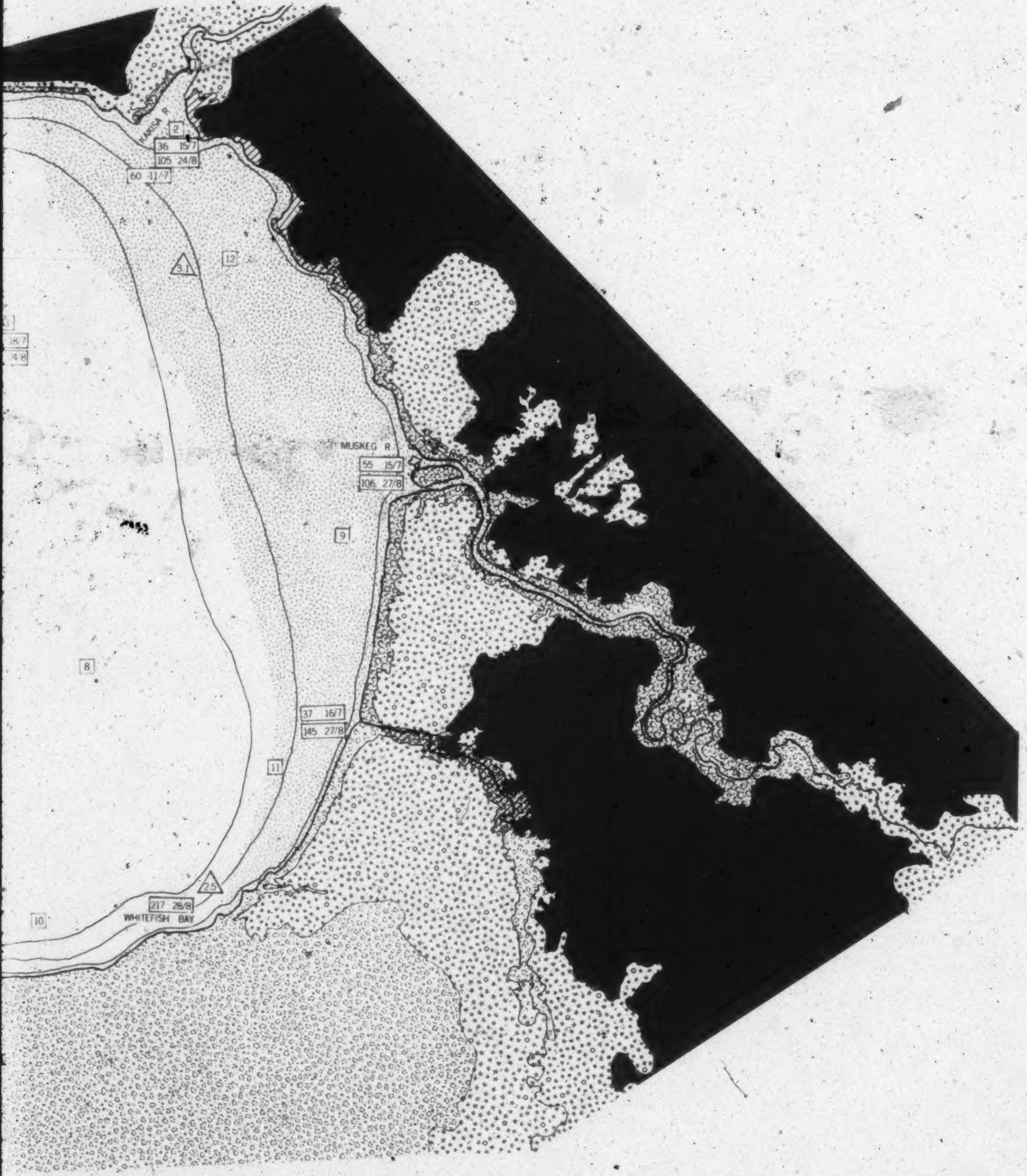
98
2.7
19
11 12/8
20
68 12/8
KAKISA LAKE
17
14 21/8
52 22/8
15
126 23/8
21
141 12/8
3.8
1
2
ILES
50 21/8
18
DEEP BAY
67 22/8
2.9
1.9
6
39 23/8
TATHLINA R

3 of



KAKISA Rᴿ
1
2
36 15/7
105 24/8
60 14/7
3.1
13
2.7
119 23/8
3.1
12
14
98 22/8
3
159 18/7
59 24/8
MUSKEG R
55 15/7
106 27/8
9
15
126 23/8
4
68 24/8
8
37 16/7
115 27/8
11
7
5
2.5
217 28/8
WHITEFISH BAY
10
1.9
2.0
39 23/8
6
ATHLINA R

4 of 4.


KAKISA R.
2
36 15/7
105 24/8
60 11/7
3.1
12
18/7
4/8
MUSKEG R.
55 15/7
106 27/8
9
8
37 16/7
145 27/8
11
2.5
217 28/8
WHITEFISH BAY
10

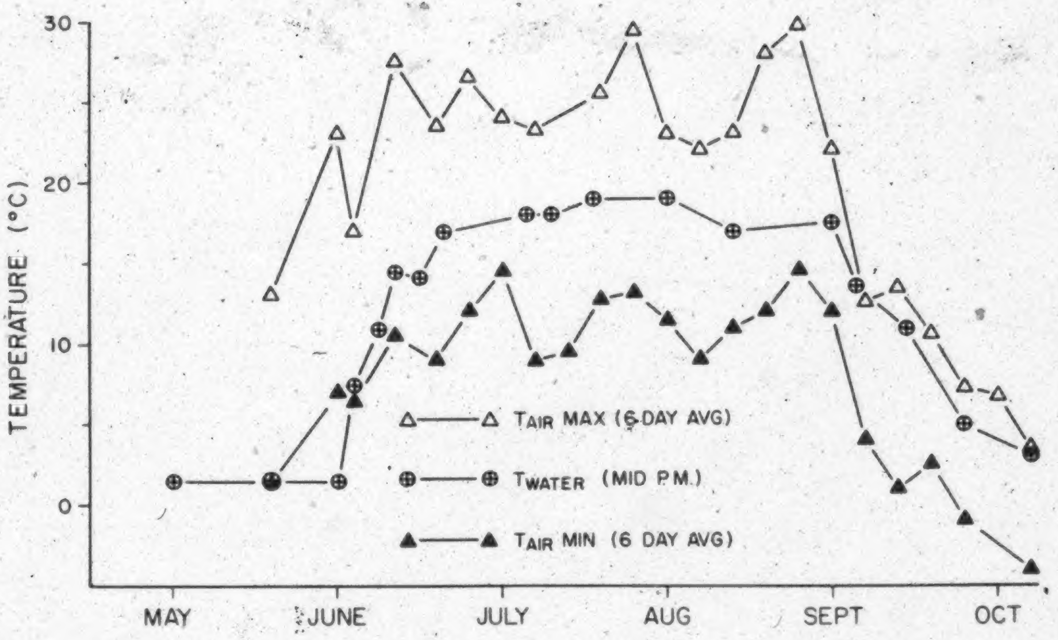


Figure 3. Minimum and maximum air temperatures and daytime lake temperatures. Air temperatures are six day averages. Water temperatures are point measurements or averages of point measurements normally taken in mid-afternoon.

7

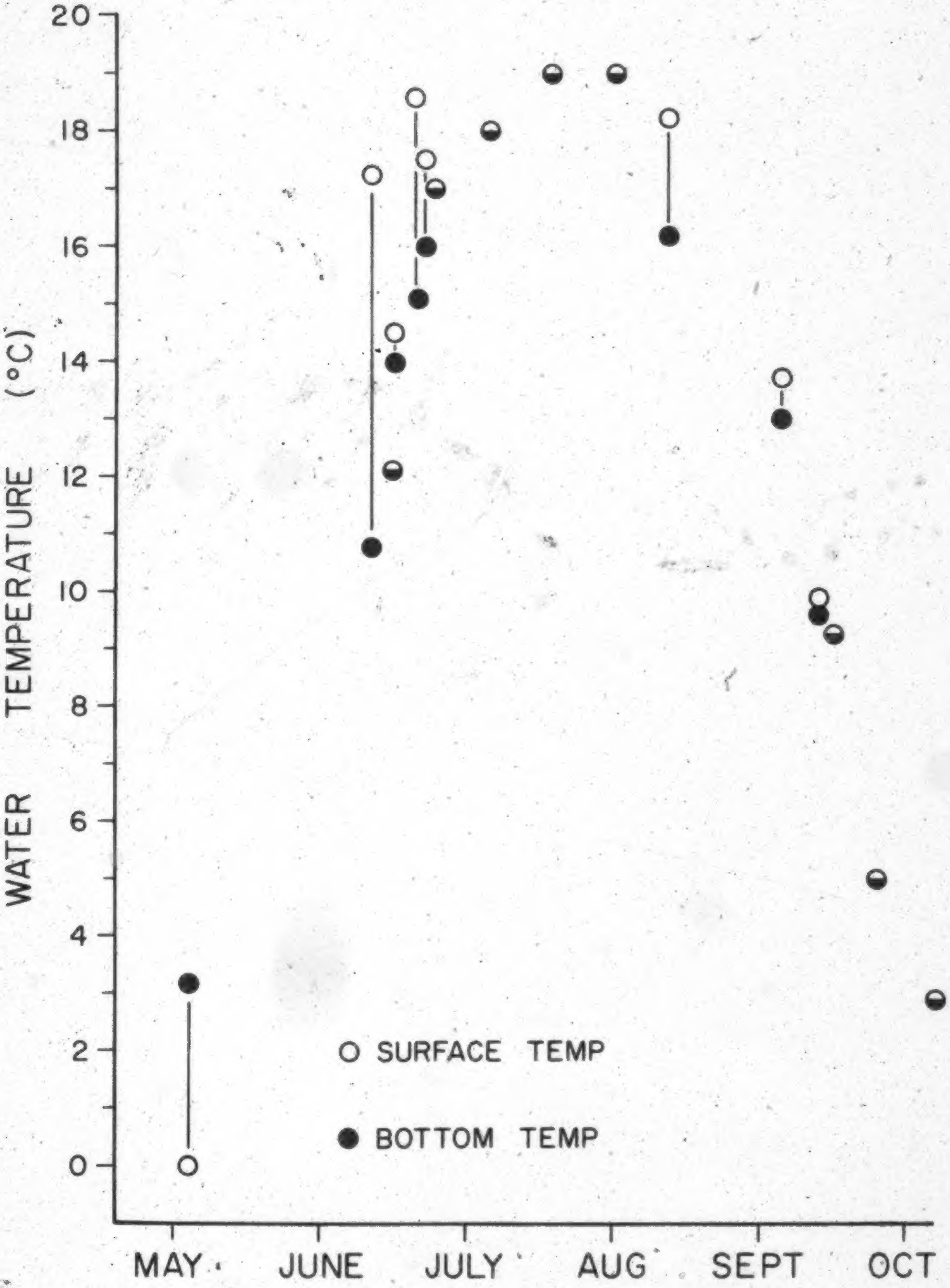


Figure 4. Surface and bottom temperatures of Kakisa Lake. Water temperatures are point measurements or averages of point measurements normally taken in mid-afternoon.

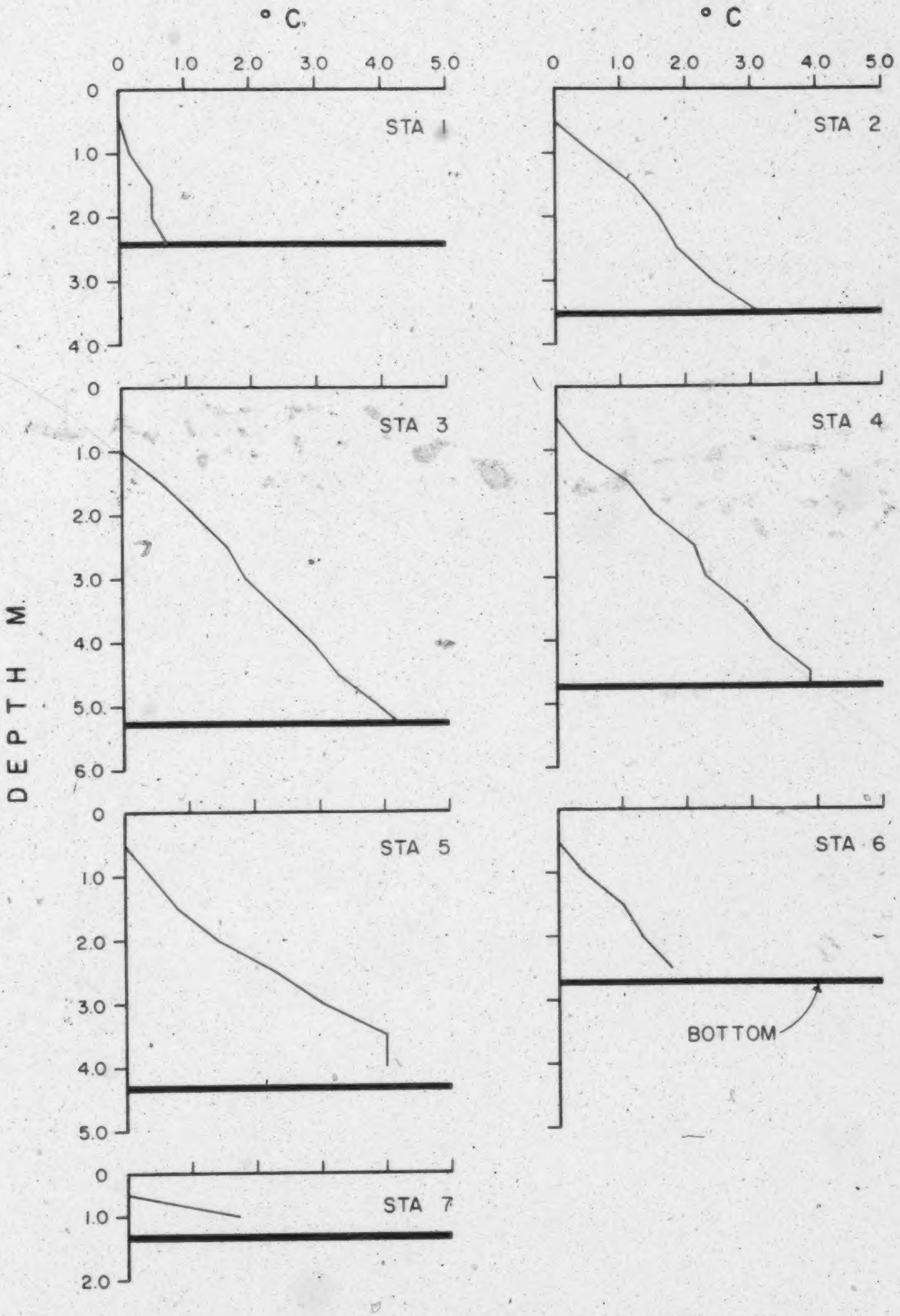


Figure 5. Temperature profiles under ice, May 7, 1972. Locations of stations are shown on Figure 1.

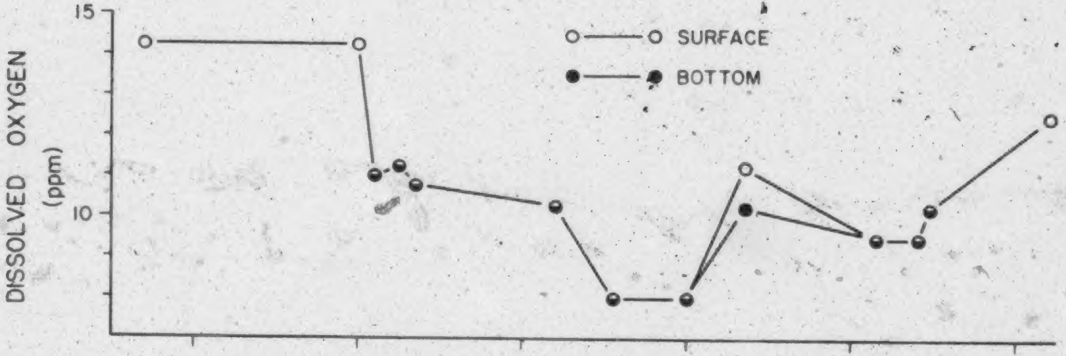


Figure 6. Absolute dissolved oxygen levels (ppm). Late April value is beneath ice cover. Final October value is less than 48 hours before freeze-up.

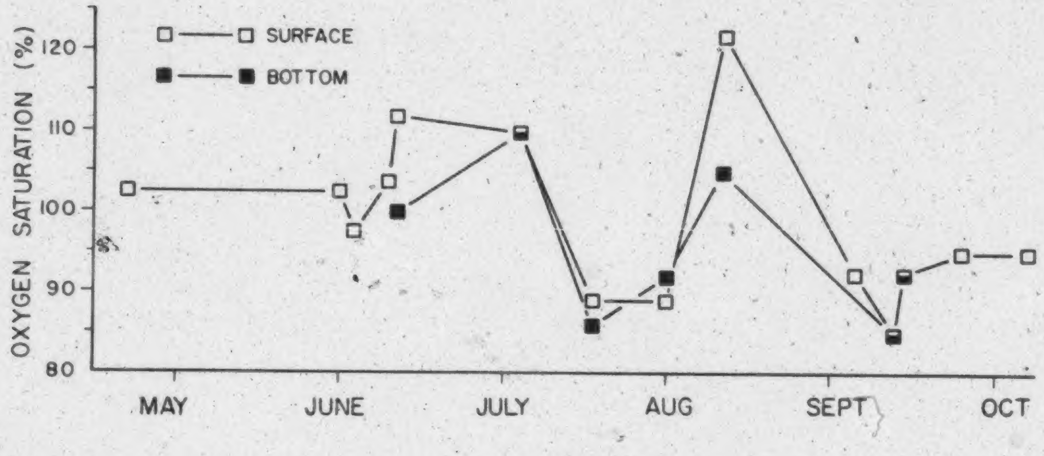


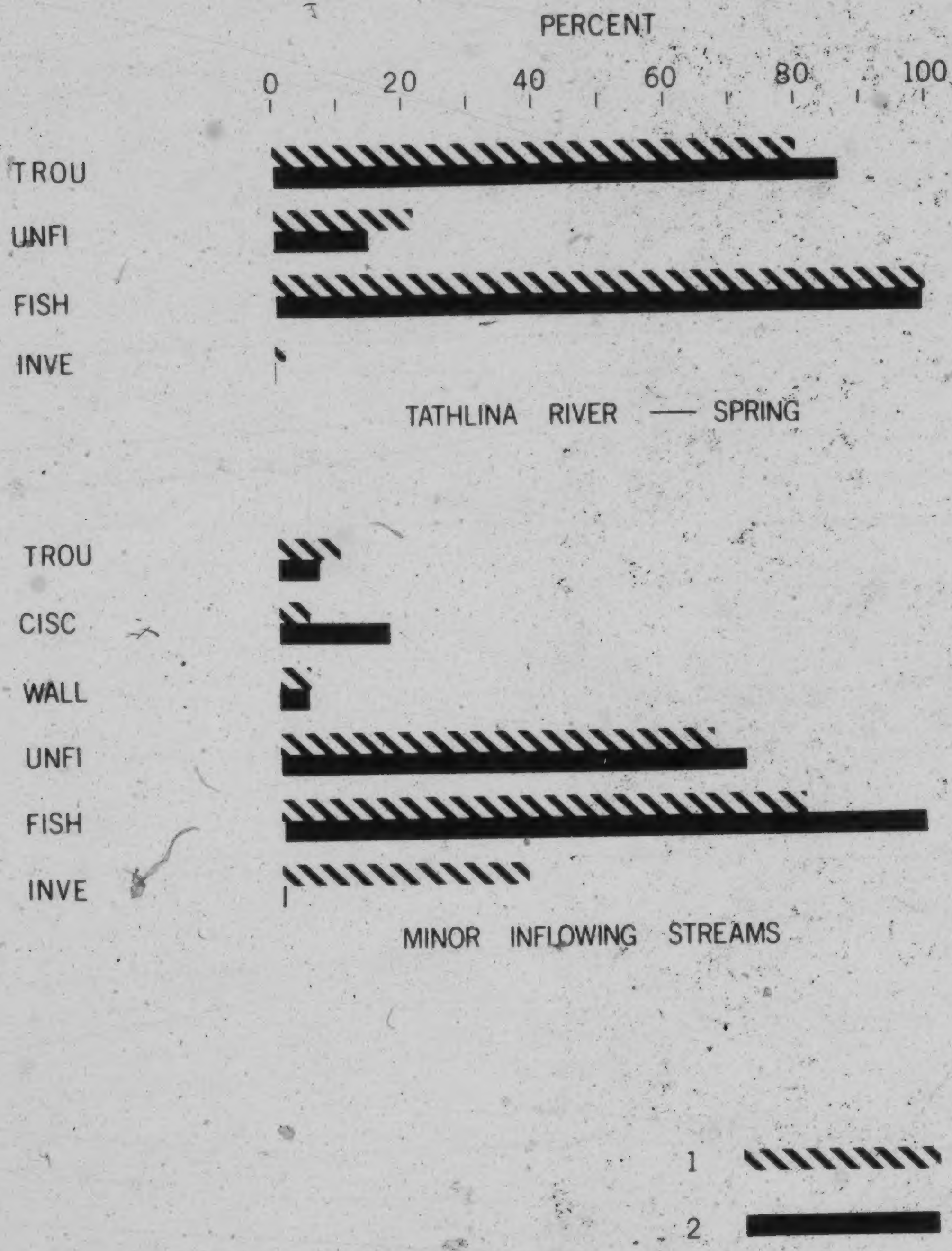
Figure 7. Percent saturation of dissolved oxygen.

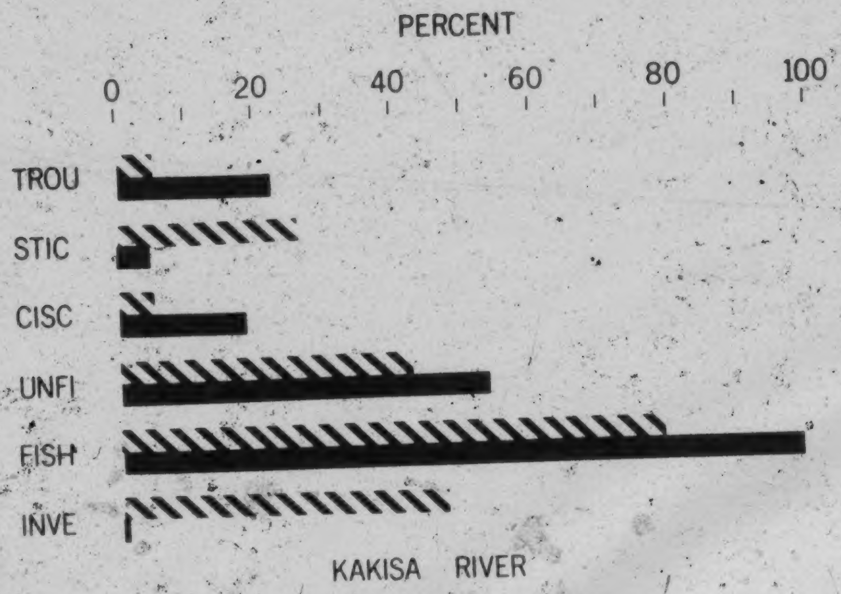
Figure 8. Stomach contents of walleye.

TROU	Trout-perch
STIC	Sticklebacks
CISC	Ciscoes
WALL	Walleye
UNFI	Unidentified fish
FISH	Fish total
INVE	Invertebrate total

1 $$\frac{\text{No. of fish containing organism}}{\text{Total No. of fish examined}} \times 100$$

2 $$\frac{\text{Total wt. of item in all stomachs}}{\text{Total wt. of all food items in all stomachs}} \times 100$$


PERCENT
0
20
40
60
80
100
TROU
UNFI
FISH
INVE
TATHLINA RIVER — SPRING
TROU
CISC
WALL
UNFI
FISH
INVE
MINOR INFLOWING STREAMS
1
2



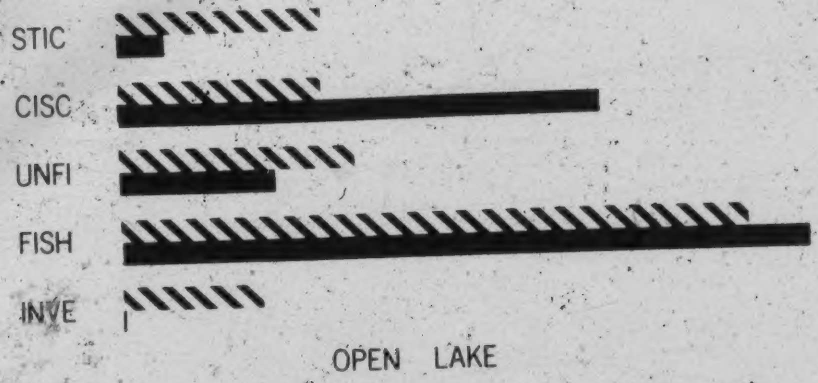


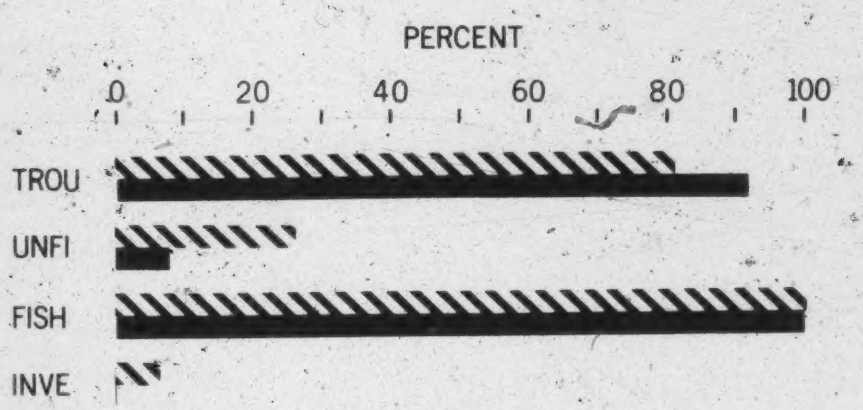
Figure 8 (Continued)

Figure 9. Stomach contents of northern pike.

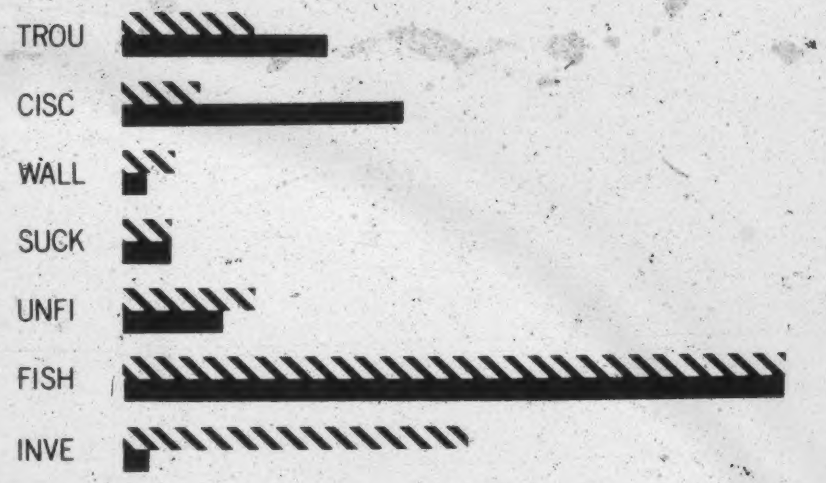
TROU	Trout-perch
STIC	Sticklebacks
CISC	Ciscoes
WALL	Walleye
SUCK	White suckers
BURB	Burbot
UNFI	Unidentified fish
FEGG	Fish eggs
FISH	Fish total
INVE	Invertebrate total

1 $$\frac{\text{No. of fish containing organism}}{\text{Total No. of fish examined}} \times 100$$

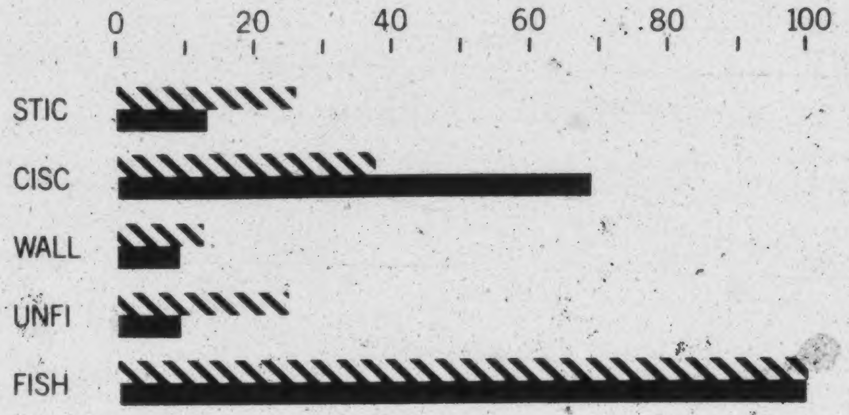
2 $$\frac{\text{Total wt. of item in all stomachs}}{\text{Total wt. of all food items in all stomachs}} \times 100$$



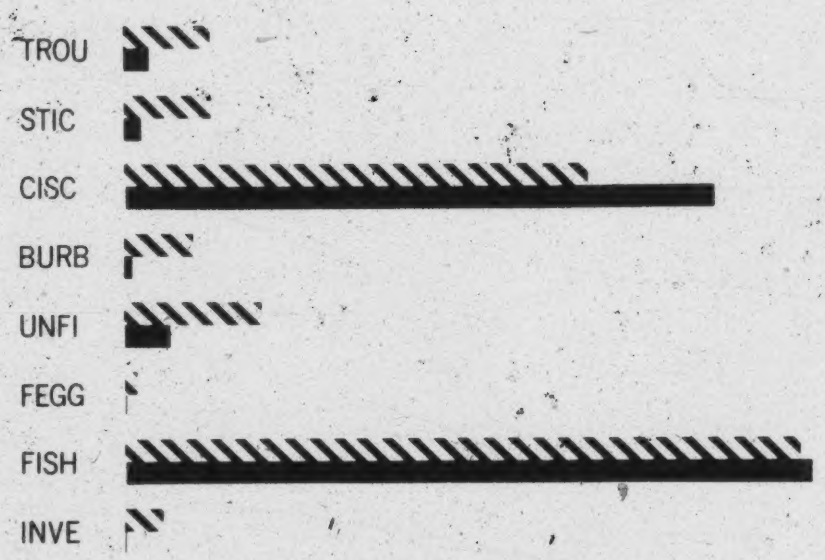
TATHLINA RIVER —— SPRING



MINOR INFLOWING STREAMS



KAKISA RIVER



OPEN LAKE

Figure 9 (Continued)

Figure 10. Stomach contents of lake ciscoes.

CLAD	Cladocera
COPE	Copepoda
ZOOP	Zooplankton total
OTHE	Other (non-planktonic) invertebrates

1 $$\frac{\text{No. of fish containing organism}}{\text{Total No. of fish examined}} \times 100$$

2 $$\frac{\text{Total wt. of item in all stomachs}}{\text{Total wt. of all food items in all stomachs}} \times 100$$

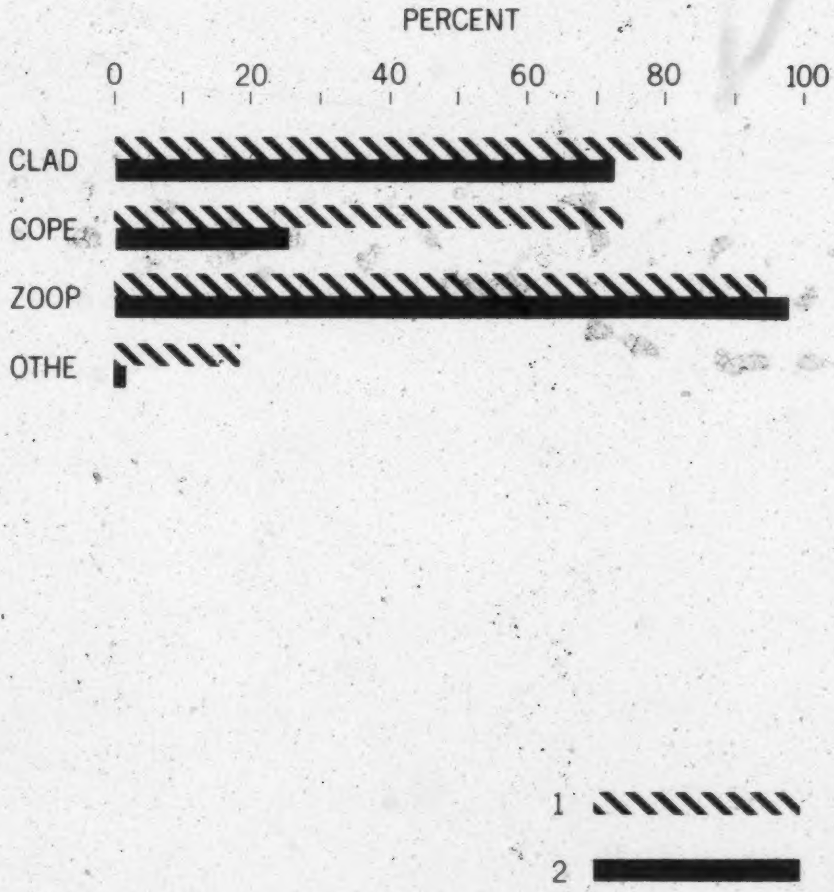
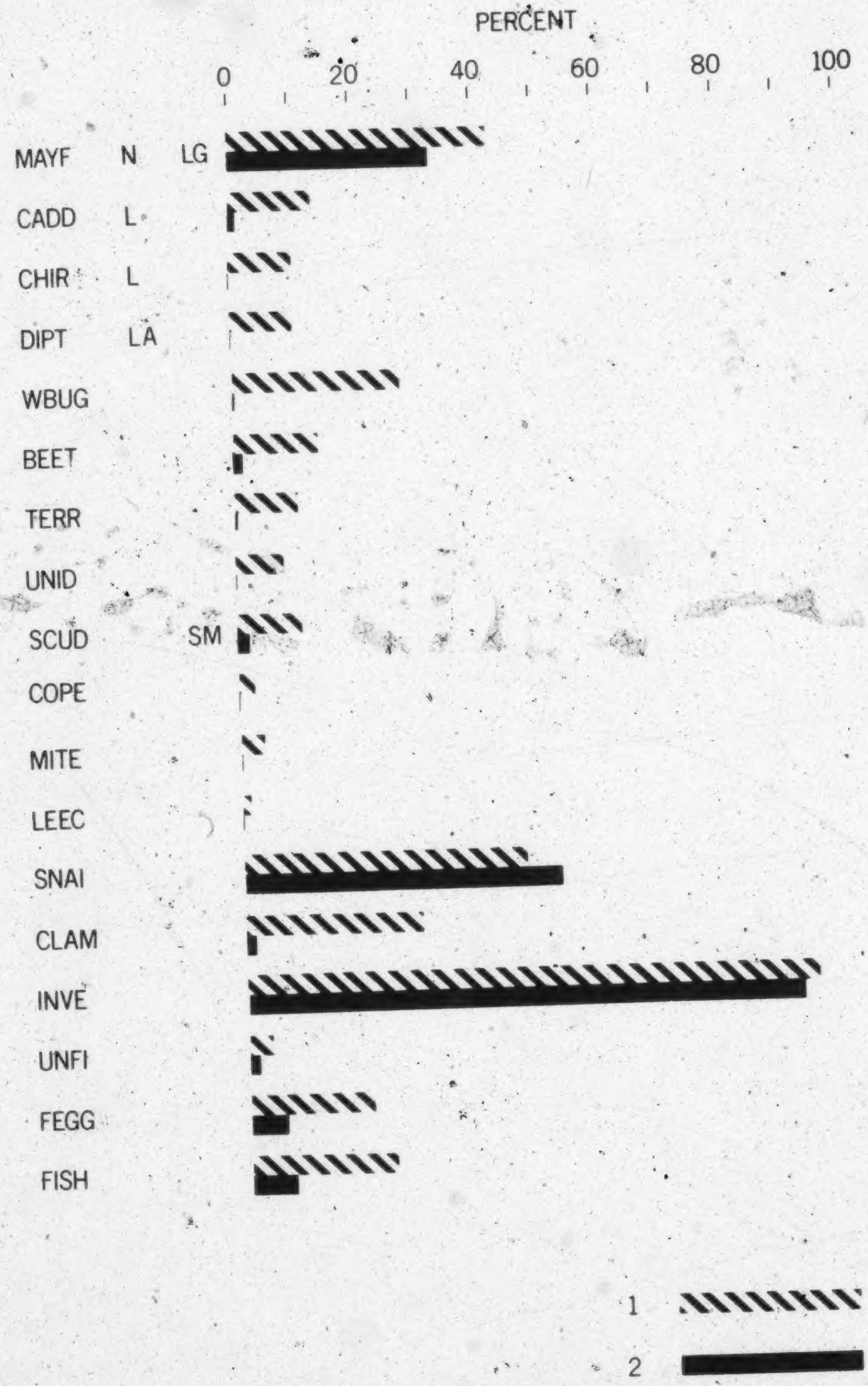

PERCENT
0
20
40
60
80
100
CLAD
COPE
ZOOP
OTHE
1
2

Figure 11. Stomach contents of lake whitefish (caught in lake).

MAYF	Mayflies (Ephemeroptera)
CADD	Caddisflies (Trichoptera)
CHIR	Chironomids (Chironomidae)
DIPT	Other Dipteran Flies (Diptera)
DAMS	Damselflies (Zygoptera)
WBUG	Water bugs (Hemiptera)
BEET	Beetles (Coleoptera)
TERR	Terrestrial insects
UNID	Unidentified insects
SCUD	Scuds (Amphipoda)
MYSI	Mysis (Mysidacea)
CLAD	Cladocerans (Cladocera)
COPE	Copepods (Copepoda)
OSTR	Ostracods (Ostracoda)
MITE	Mites (Hydracarina)
LEEC	Leeches (Hirudinea)
SNAI	Snails (Gastropoda)
CLAM	Clams (Pelecypoda)
INVE	Invertebrate total
UNFI	Unidentified fish
FEGG	Fish eggs
FISH	Fish
N	Nymphs
L	Larvae
A	Adults
LG	Large
SM	Small

1 $$\frac{\text{No. of fish containing organism}}{\text{Total No. of fish examined}} \times 100$$

2 $$\frac{\text{Total wt. of item in all stomachs}}{\text{Total wt. of all food items in all stomachs}} \times 100$$


PERCENT
0
20
40
60
80
100
MAYF N LG
CADD L
CHIR L
DIPT LA
WBUG
BEET
TERR
UNID
SCUD SM
COPE
MITE
LEEC
SNAI
CLAM
INVE
UNFI
FEGG
FISH
1
2

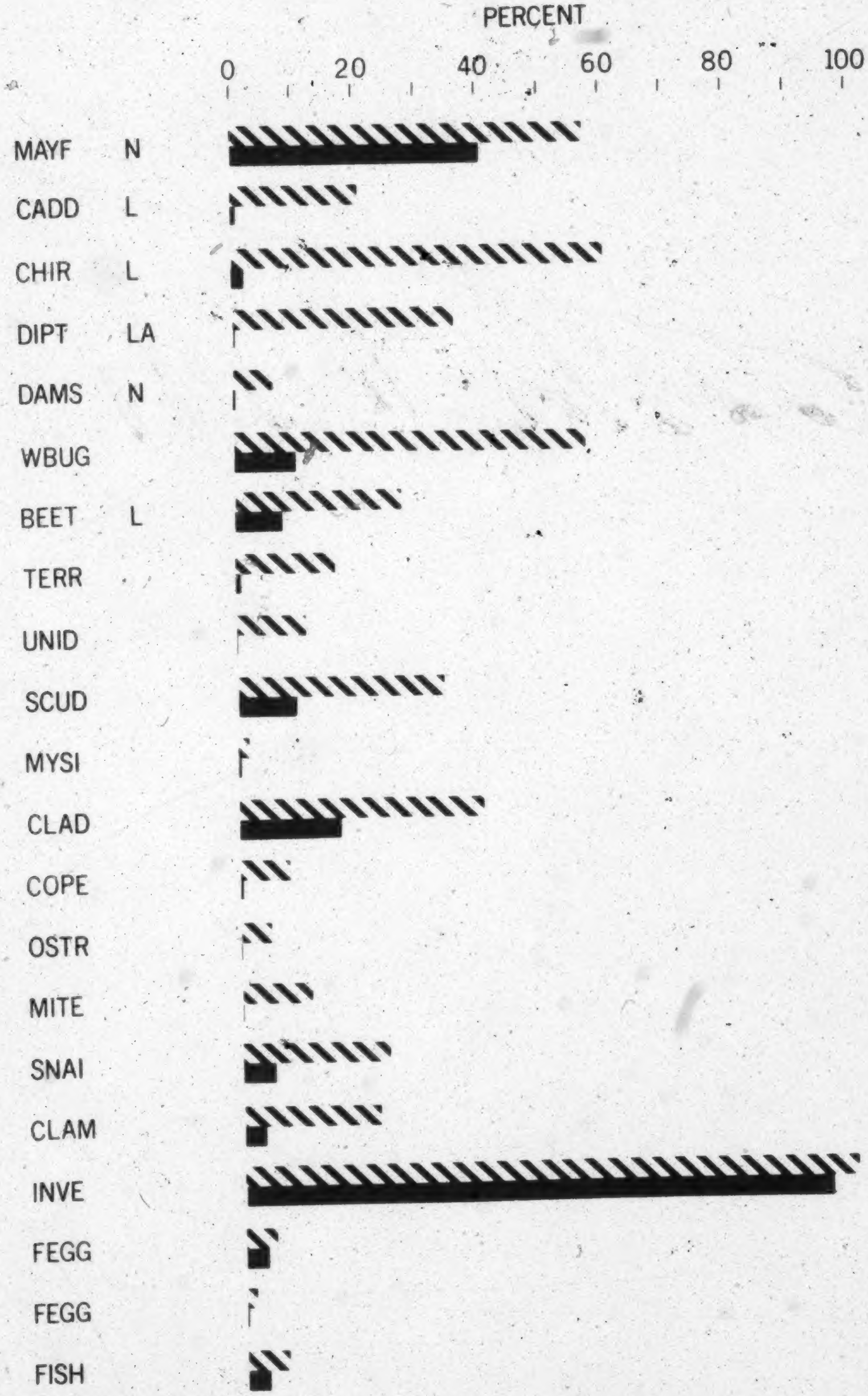


Figure 11 (Continued) Stomach contents of lake whitefish (caught in streams)

Figure 12. Stomach contents of white suckers (caught in streams).

MAYF	Mayflies (Ephemeroptera)
CADD	Caddisflies (Trichoptera)
STON	Stoneflies (Plecoptera)
CHIR	Chironomids (Chironomidae)
DIPT	Other dipterans (Diptera)
DRAG	Dragonflies (Anizoptera)
DAMS	Damselflies (Zygoptera)
WBUG	Water bugs (Hemiptera)
BEET	Beetles (Coleoptera)
TERR	Terrestrial insects
UNID	Unidentified insects
SCUD	Scuds (Amphipoda)
CLAD	Cladocerans (Cladocera)
MITE	Mites (Hydracarina)
SNAI	Snails (Gastropoda)
CLAM	Clams (Pelecypoda)
FEGG	Fish eggs

N	Nymphs
L	Larvae
A	Adults

LG	Large
SM	Small

1 $$\frac{\text{No. of fish containing organism}}{\text{Total No. of fish examined}} \times 100$$

2 $$\frac{\text{Total wt. of item in all stomachs}}{\text{Total wt. of all food items in all stomachs}} \times 100$$

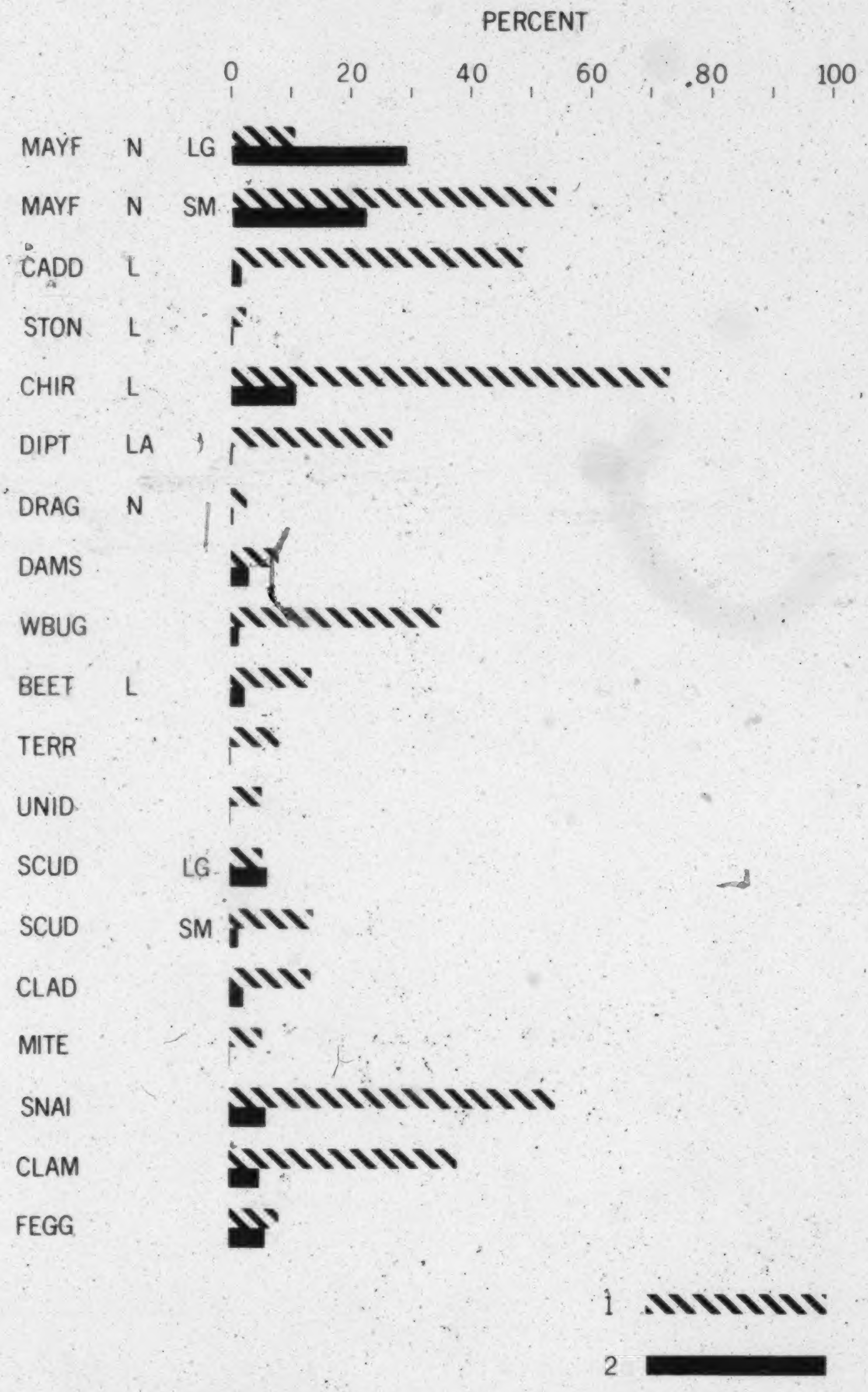

PERCENT
0
20
40
60
80
100
MAYF N LG
MAYF N SM
CADD L
STON L
CHIR L
DIPT LA
DRAG N
DAMS
WBUG
BEET L
TERR
UNID
SCUD LG
SCUD SM
CLAD
MITE
SNAI
CLAM
FEGG
1
2

Figure 13. Weight-age relationships for walleye, pike, lake whitefish and white suckers. Source: unpublished data of Fisheries Research Board study of Kakisa Lake fishery (August 13-28, 1968).

1	Pike
2	White Sucker
3	Lake Whitefish
4	Walleye

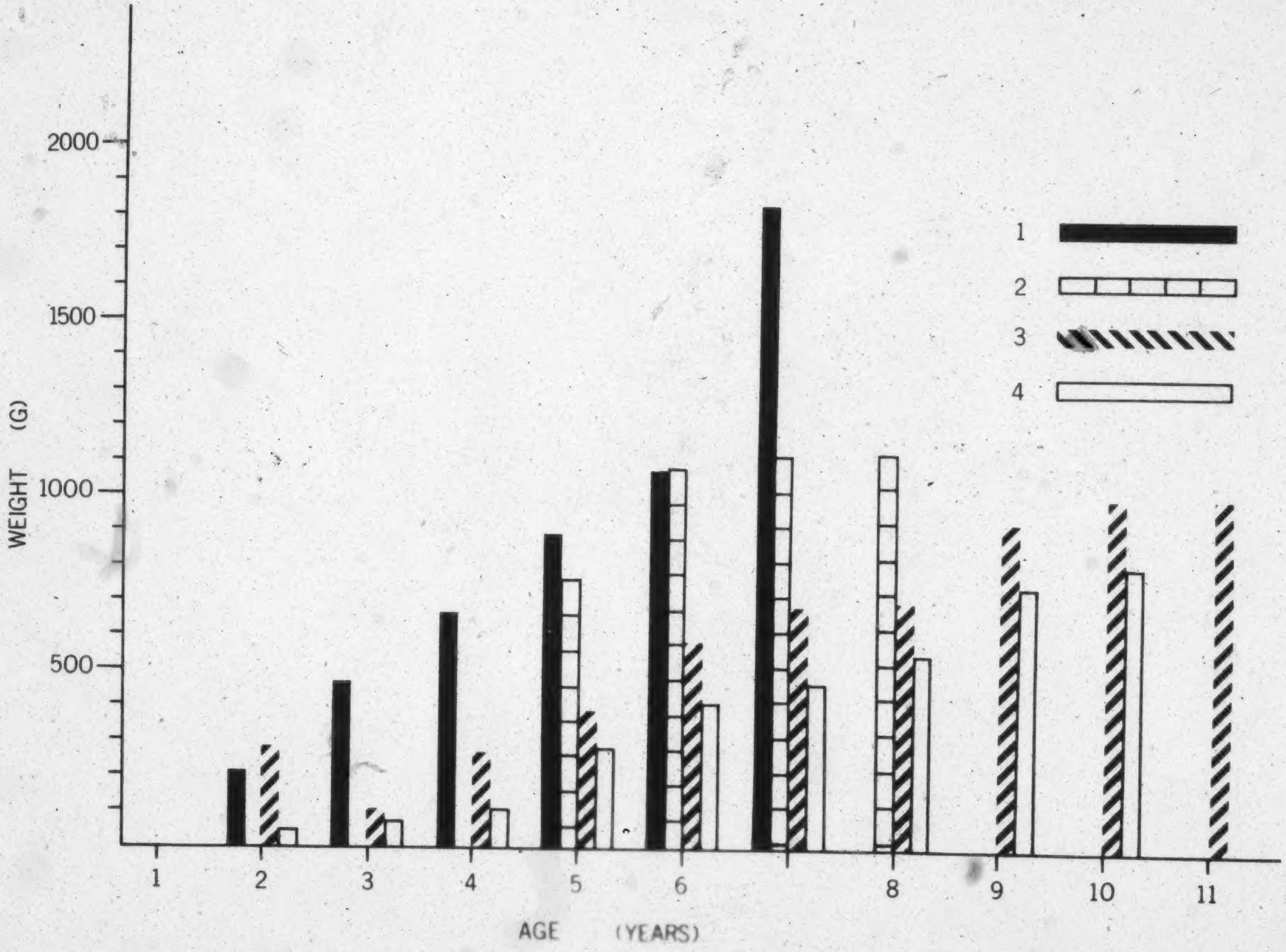

WEIGHT (G)
2000
1500
1000
500
AGE (YEARS)
1
2
3
4
5
6
8
9
10
11
1
2
3
4

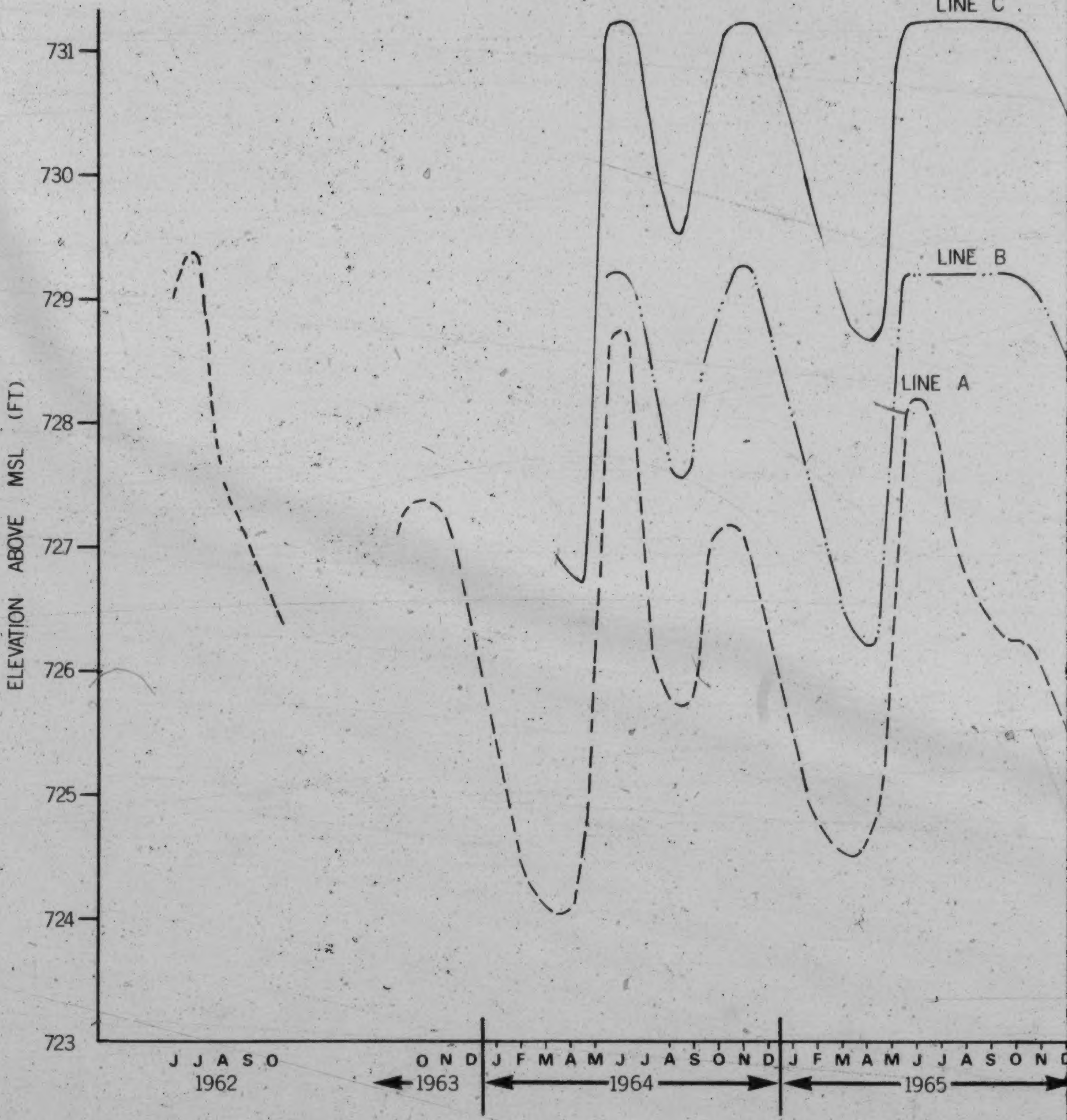
Figure 14. Kakisa Lake water levels for period of record. Source: C. Andersen, Underwood McLellan and Associates Ltd.

Line A	Actual levels
Line B	Hypothetical case of 6 feet of live storage (Elevation 729.2-723.2)
Line C	Hypothetical case of 8 feet of live storage (Elevation 731.2-723.2)

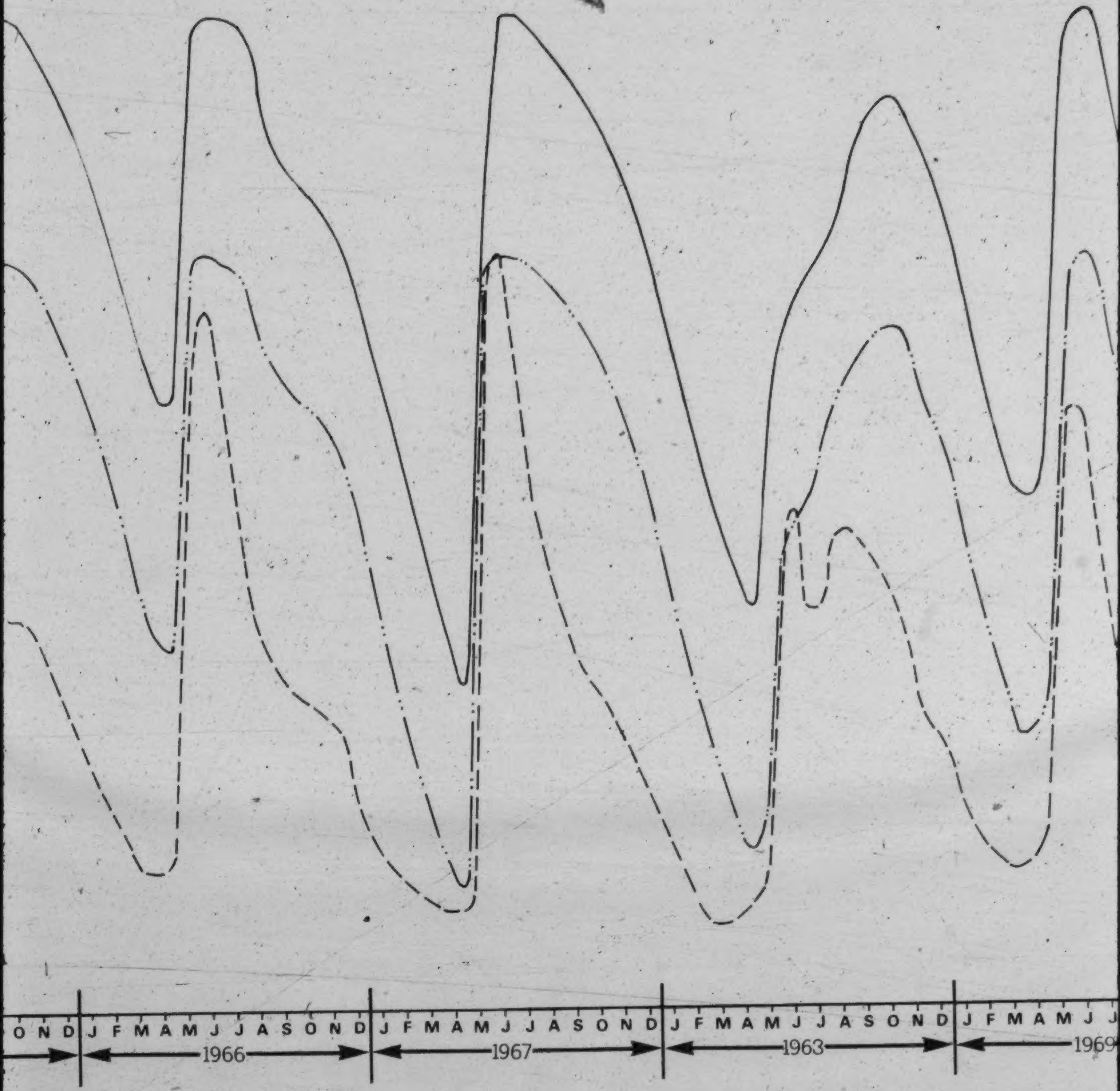
Assumed firm flow for Lines B and C.

September-April	1250 cfs
May-August	1500 cts

1 of


LINE C
LINE B
LINE A
ELEVATION ABOVE MSL (FT)
731
730
729
728
727
726
725
724
723
J J A S O
1962
O N D
1963
J F M A M J J A S O N D
1964
J F M A M J J A S O N D
1965

2 of


O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J
1966
1967
1963
1969

3 of 3

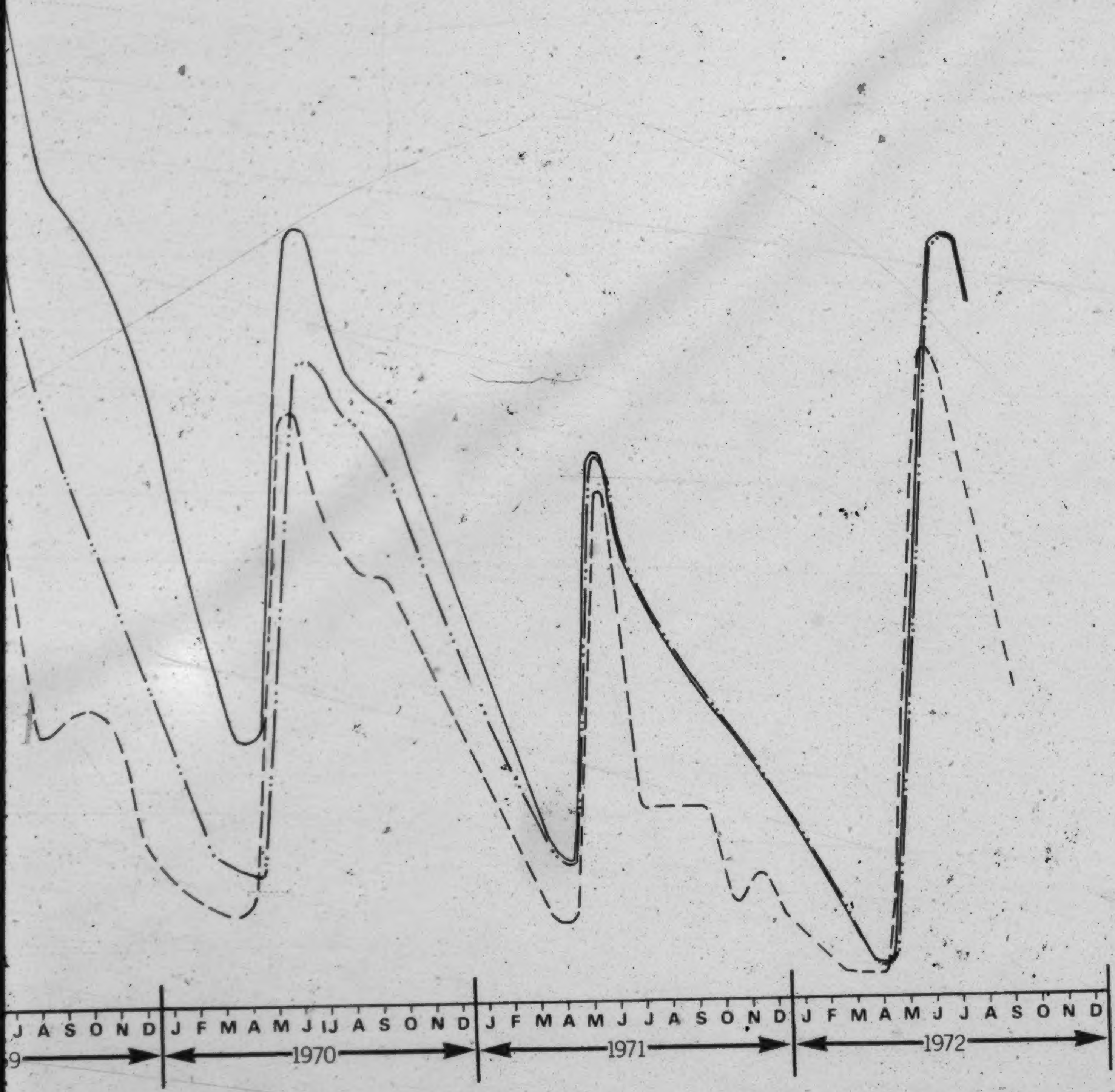

J A S O N D
J F M A M J J A S O N D
J F M A M J J A S O N D
J F M A M J J A S O N D
9
1970
1971
1972

Figure 15. Frequency distributions of middle-of-the-month water levels (in one-foot intervals) for the period of record. Note that class sizes are not all equal because of the incompleteness of the record. Schemes A, B and C refer to the water level regimes indicated by Lines A, B and C in Figure 14.

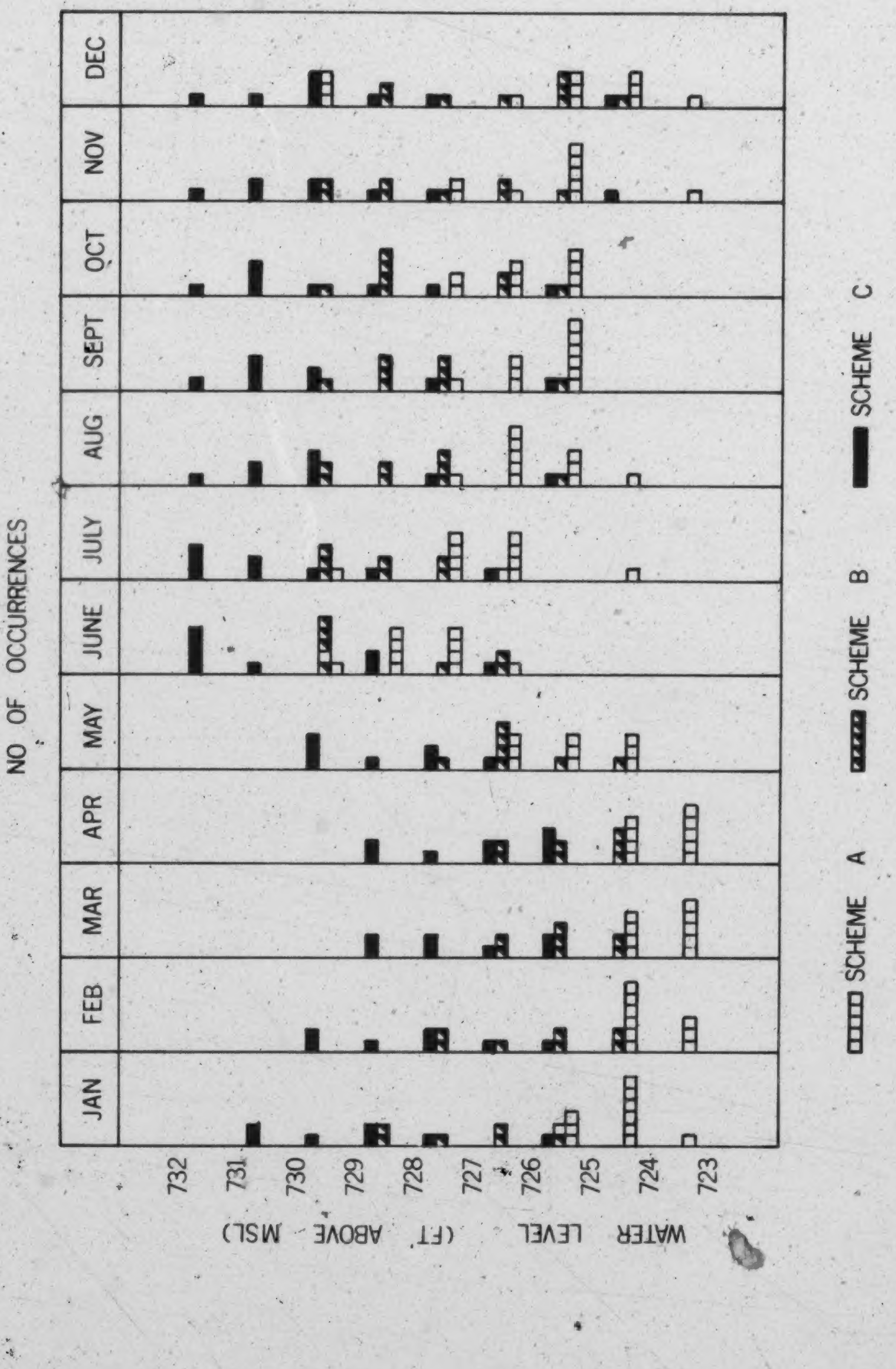

NO OF OCCURRENCES
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
732
731
730
729
728
727
726
725
724
723
WATER LEVEL (FT ABOVE MSL)
SCHEME A
SCHEME B
SCHEME C

Figure 16. Middle-of-the-month water levels from June 15 to September 15 for the period of record.

1	Scheme A (natural water level)
2	Increase in water level caused by hypothetical Scheme B (6 feet of live storage)
3	Additional increase in water level over that of Scheme B caused by hypothetical Scheme C (8 feet of live storage)

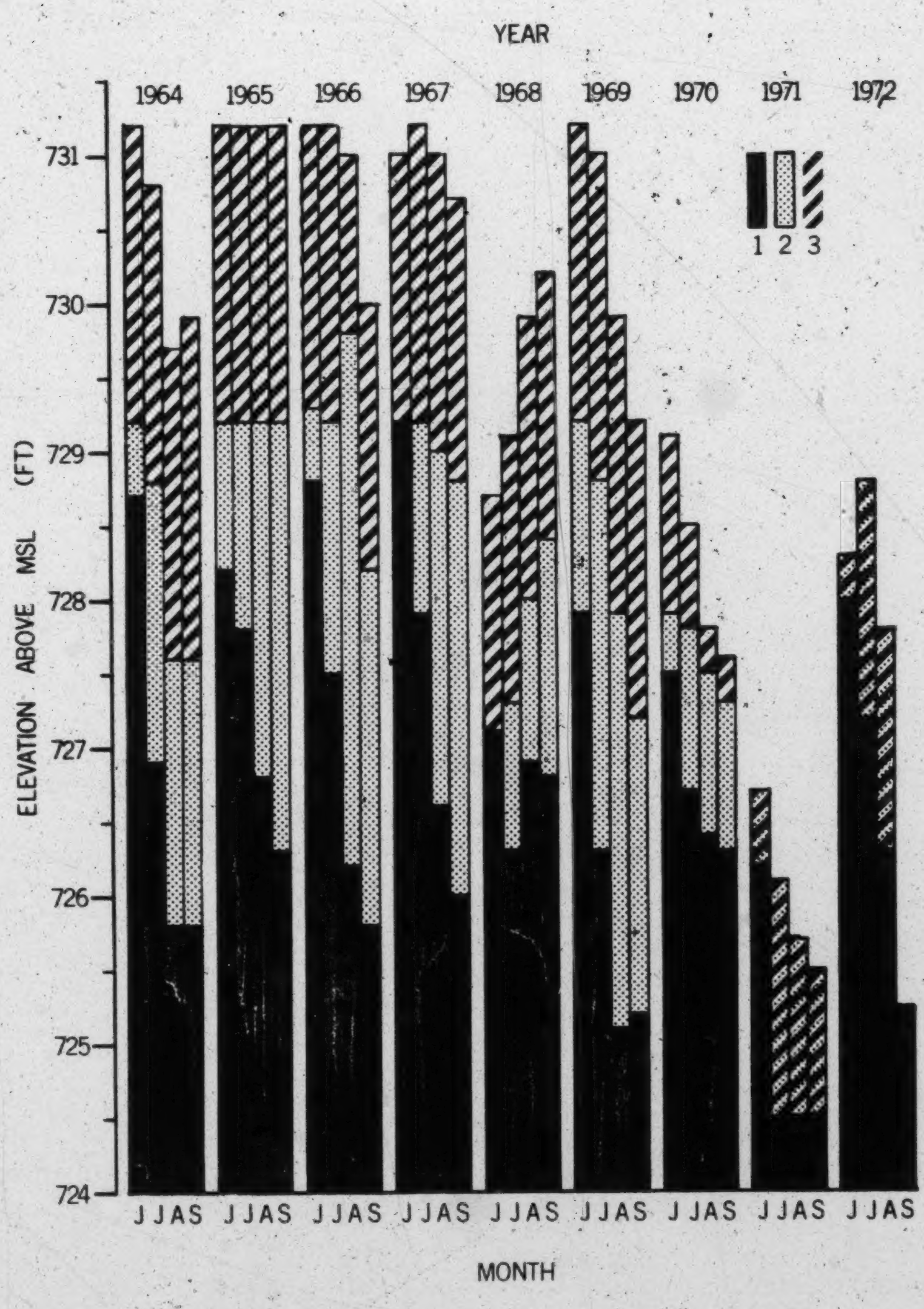
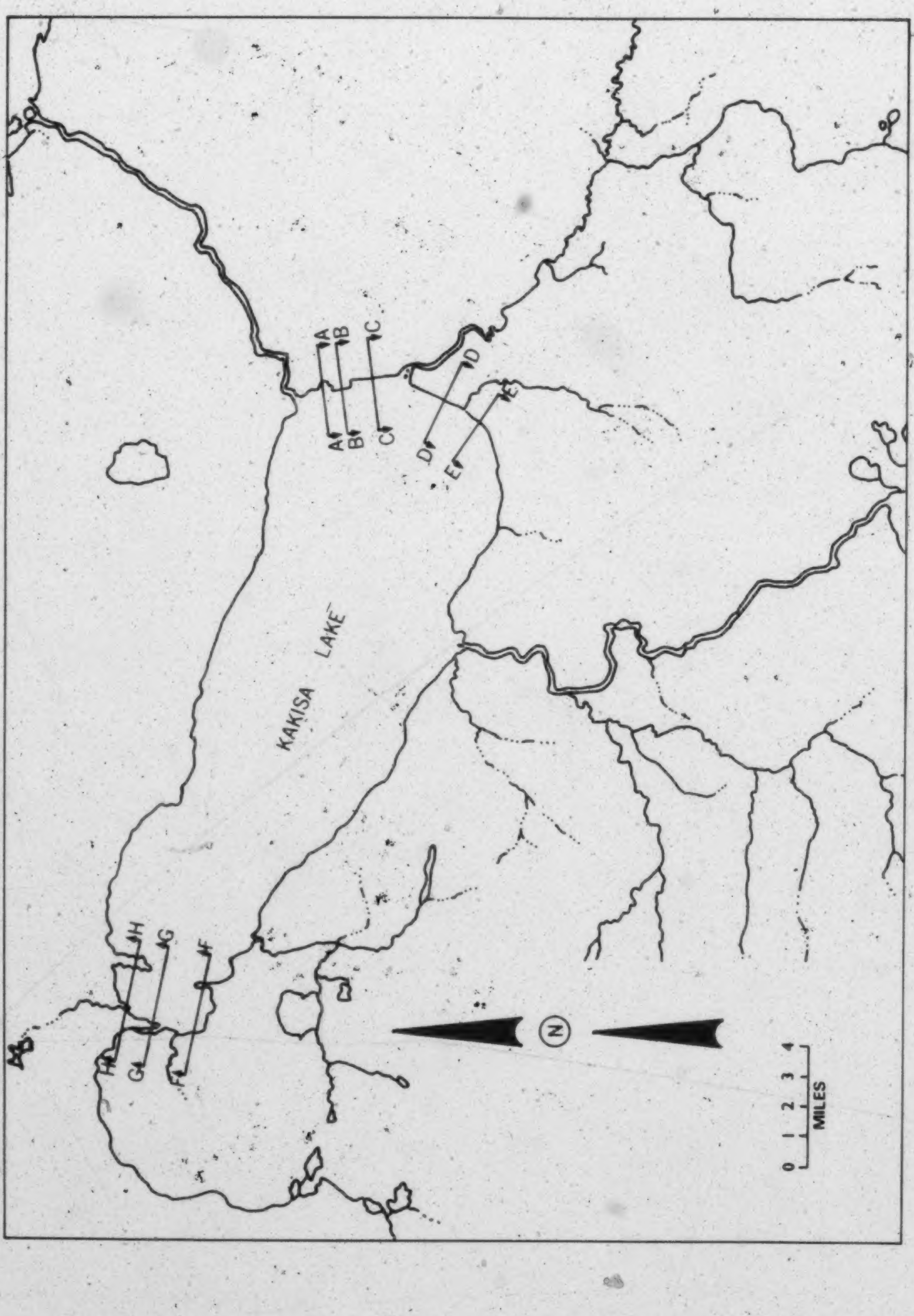

YEAR
1964
1965
1966
1967
1968
1969
1970
1971
1972
1
2
3
ELEVATION ABOVE MSL (FT)
731
730
729
728
727
726
725
724
J J A S
J J A S
J J A S
J J A S
J J A S
J J A S
J J A S
J J A S
J J A S
MONTH

Figure 17. Location map of cross-sections shown in Figure 18.


A
A
B
B
C
C
D
D
E
E
F
F
G
G
H
H
KAKISA LAKE
N
0 1 2 3 4
MILES

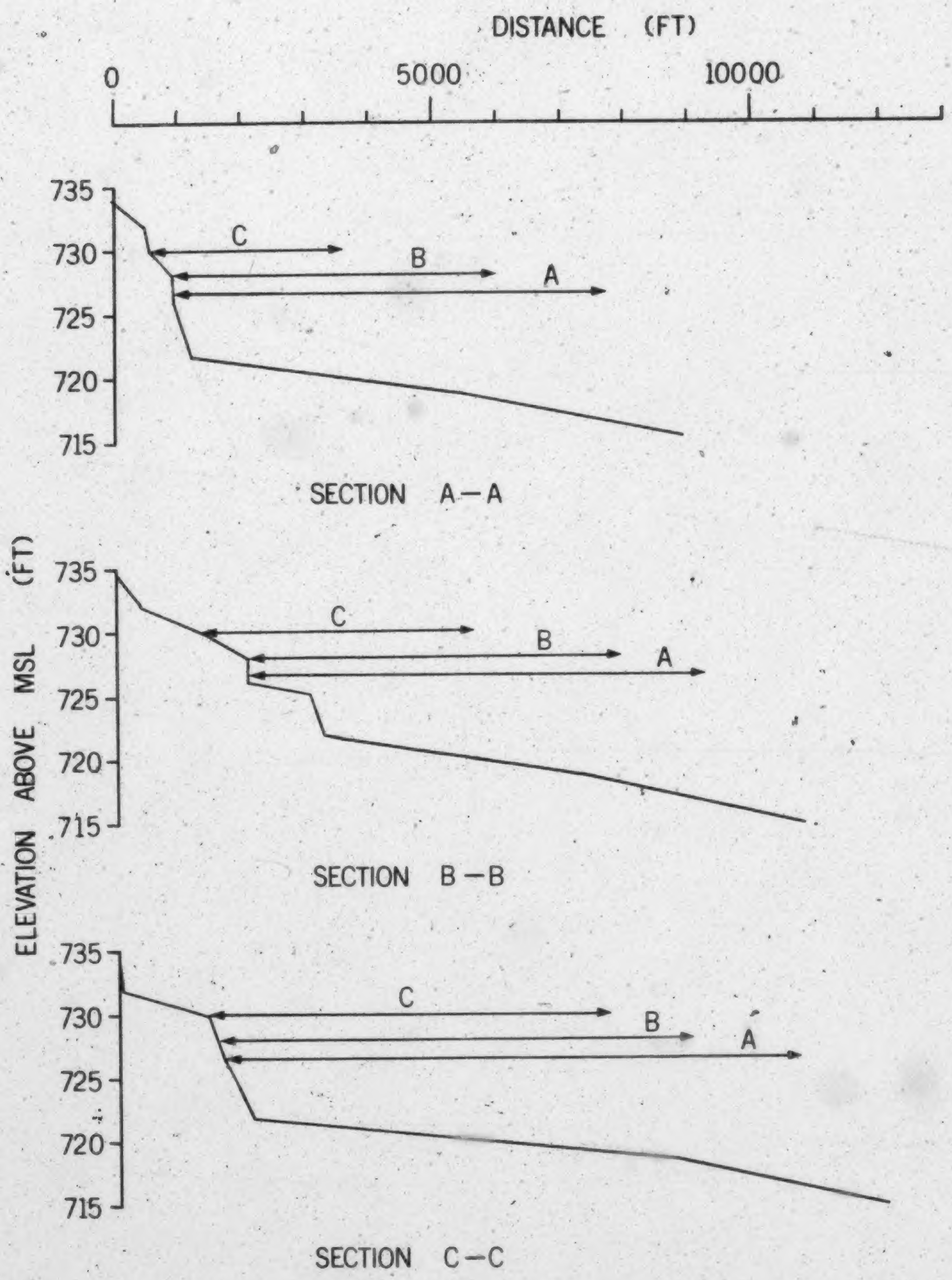
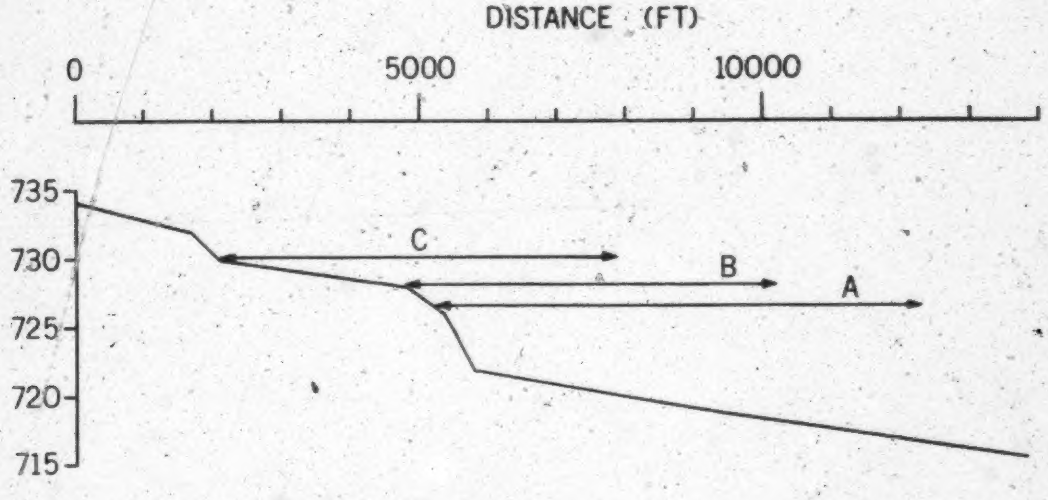
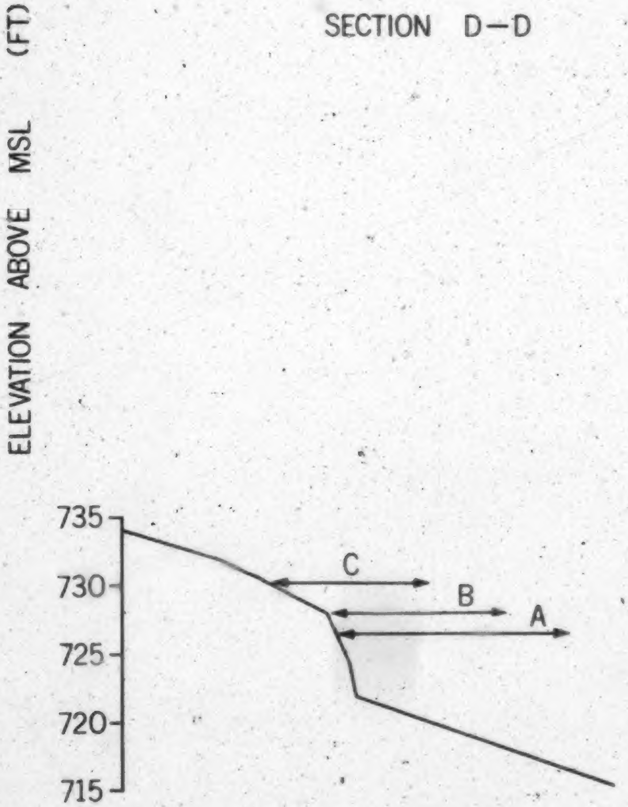


Figure 18. Typical cross-sections in the low-lying eastern and western ends of Kakisa Lake. See Figure 17 for locations

A	Median water level for Scheme A
B	Median water level for Scheme B
C	Median water level for Scheme C



SECTION D—D



SECTION E—E

Figure 18 (Continued)

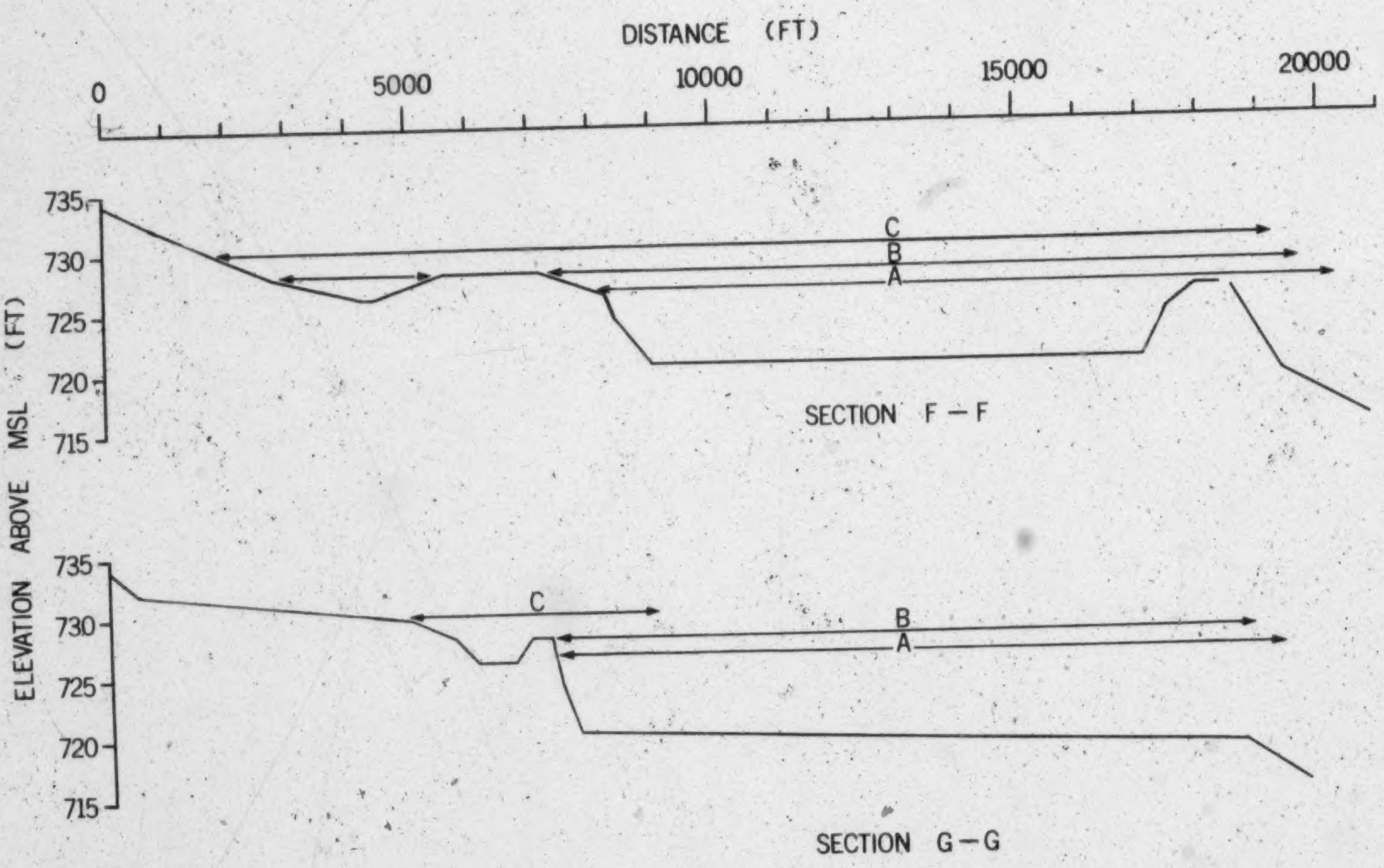


Figure 18 (Continued)

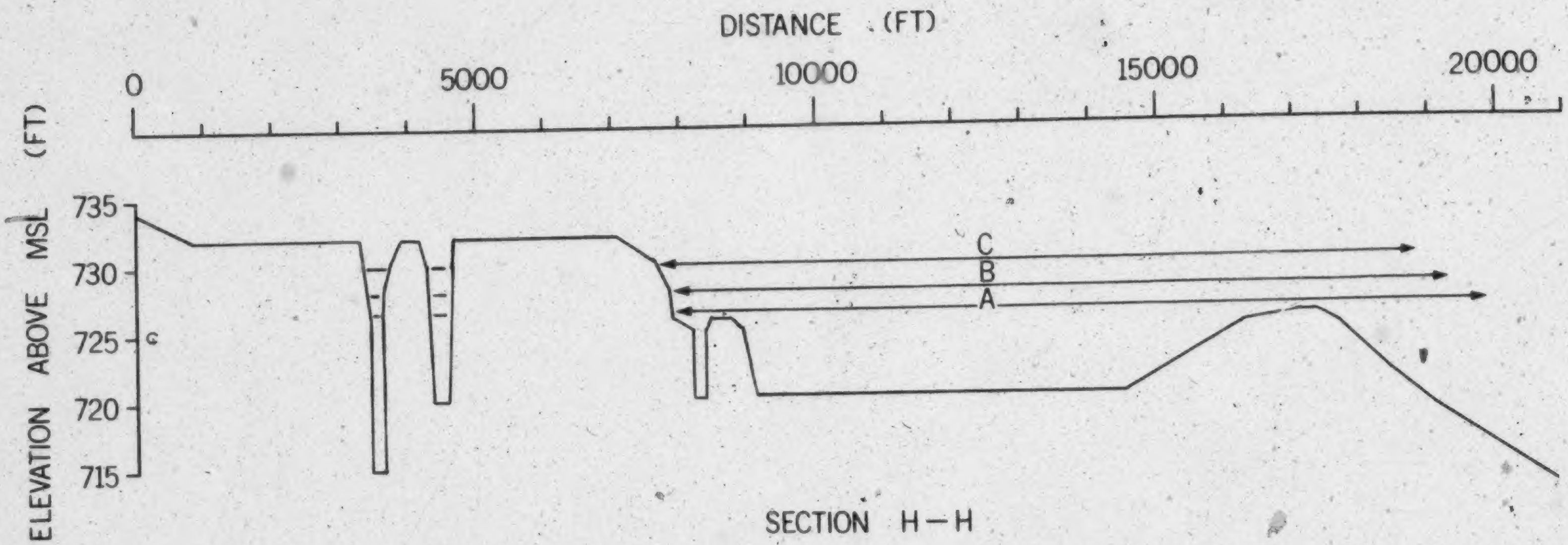


Figure 18 (Continued)

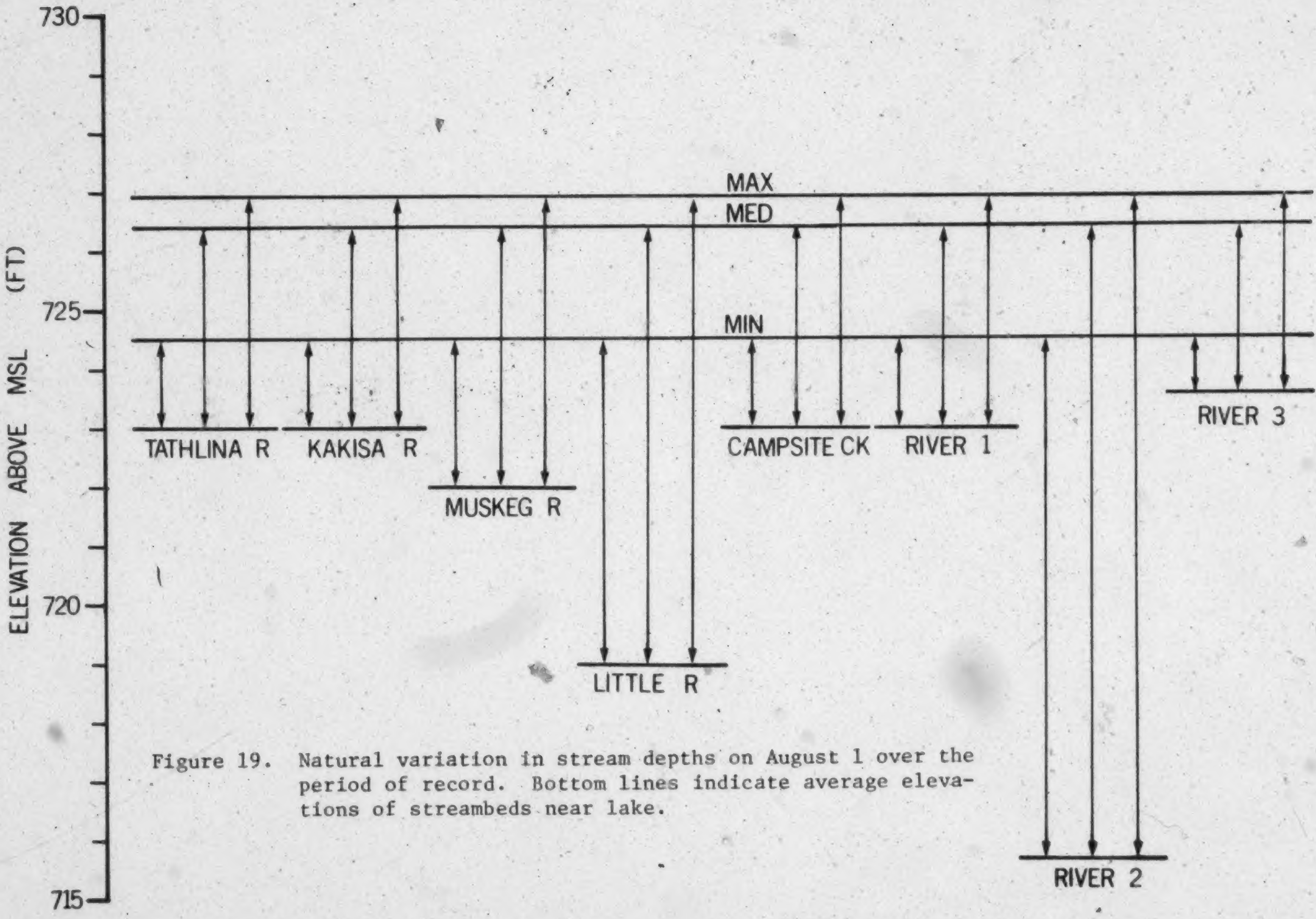


Figure 19. Natural variation in stream depths on August 1 over the period of record. Bottom lines indicate average elevations of streambeds near lake.

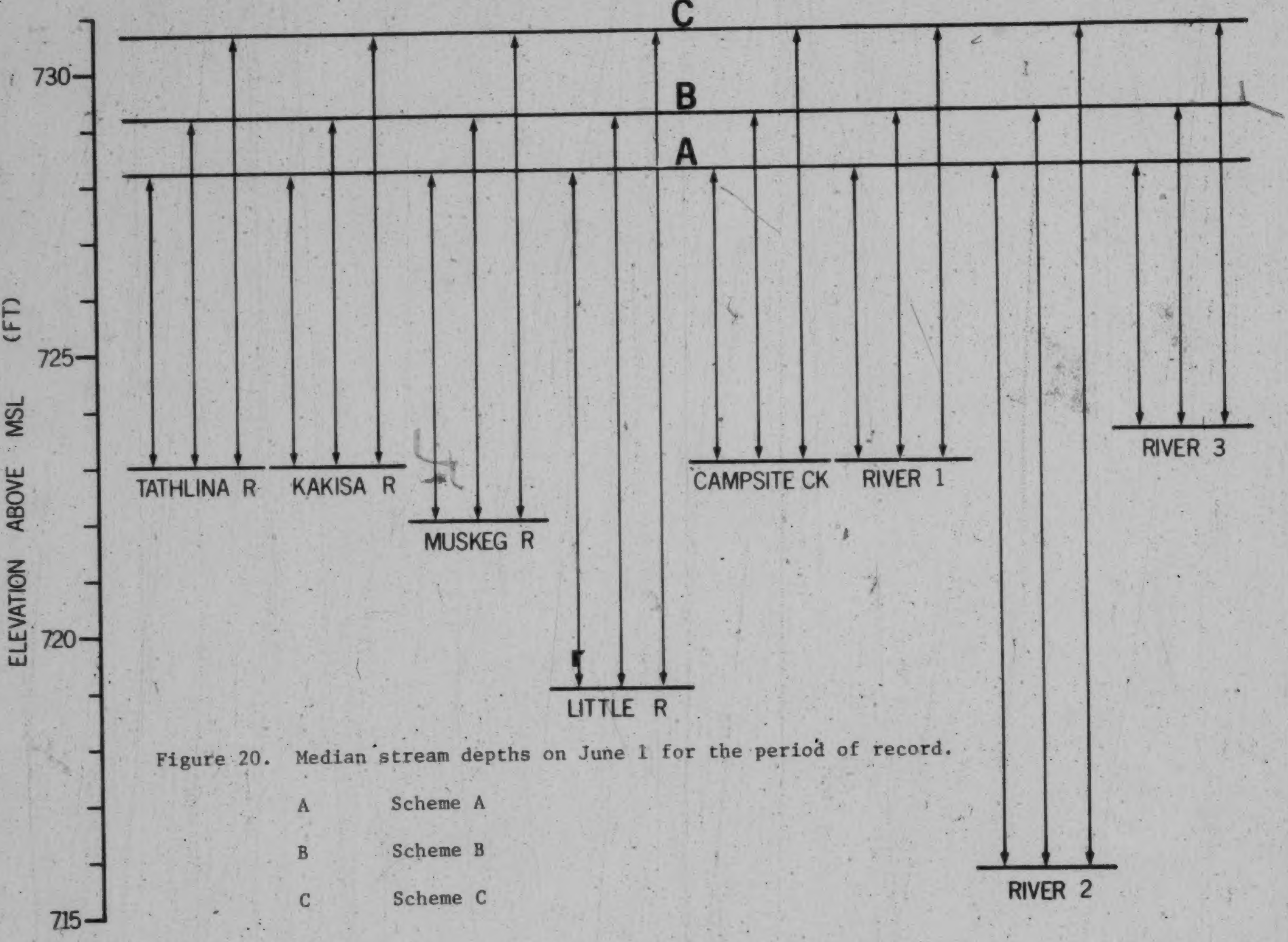


Figure 20. Median stream depths on June 1 for the period of record.

A	Scheme A
B	Scheme B
C	Scheme C

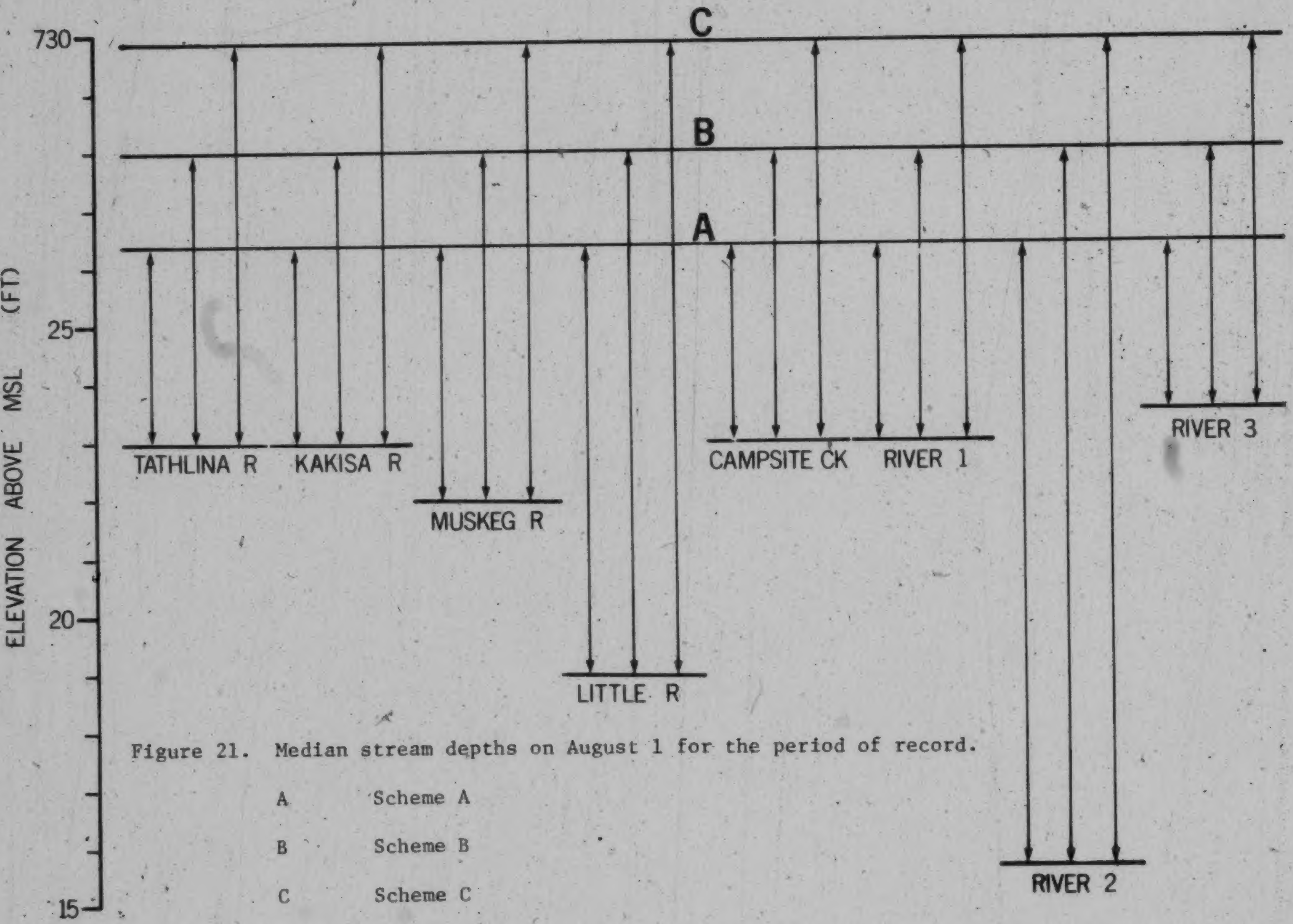


Figure 21. Median stream depths on August 1 for the period of record.

A Scheme A

B Scheme B

C Scheme C

APPENDIX I. Water chemistry analysis

Date	Location	Total alkalinity (mg/l)	Phosphate (Ortho) (mg/l)	Silica (mg/l)	Nitrate (mg/l)	Conductivity (micromho)	Dissolved Filtrable Solids (mg/l)	Iron (mg/l)	Color	Turbidity (J.T.U.)	Hardness Ca (mg/l)	Hardness Total (mg/l)	Chloride (mg/l)	Sulfate (mg/l)
Apr 16	9A Muskeg	223.8	< .05	10.0	.07	480	-	.18	-	-	152	256	10.03	-
Apr 17	9 Muskeg Mouth	196.4	< .05	8.0	.04	420	-	.36	-	-	-	-	7.09	-
Apr 17	1 mi off Muskeg Mouth	95.0	< .05	4.2	.06	230	-	.05	12	4	92	144	2.13	-
May 7	Hole 1 (Sta 9)	134.65	.15	4.6	.07	360	-	.42	37	5	129	202	2.80	30
May 7	Hole 20 (Sta 15)	123.30	.08	3.5	.05	310	-	.05	6	2	120	168	1.95	25
May 7	Hole 21 (Sta 17)	120.55	< .05	3.6	.07	300	-	.06	6	11	108	153	1.84	21
May 7	Hole 24 (Sta 26-28)	132.10	< .05	3.9	.05	350	-	.12	37	3	120	184	2.66	30
May 7	Hole 25 (Sta 29-30)	229.1	5.20	6.2	.07	530	-	.64	50	20	191	274	5.35	4
May 8	9A over ice	68.70	.30	3.2	.05	360	-	.70	205	43	129	188	4.15	64
May 8	9A under ice	66.85	.15	3.0	.03	380	-	.65	205	40	130	179	4.61	80
May 16	Sta 1	127.3	< .05	3.6	.04	320	185.3	.10	25	4	120	180	.96	40
May 16	Sta 2	124.3	< .05	3.5	.04	300	178.0	.14	42	5	114	180	1.45	39
June 8	Sta 2	90.0	< .05	2.2	.04	250	171.2	.18	35	0	92	96	.96	41
June 8	Sta 4	112.30	< .05	2.6	.04	250	135.4	.12	25	2	102	140	1.95	35
June 8	Sta 6	94.2	< .05	3.0	.02	240	109.9	.42	50	5	94	128	0	37
June 11	Sta 2	95.5	< .05	2.5	.04	270	124.9	.14	42	5	88	144	.96	41
June 11	Sta 4 Top	99.0	< .05	2.5	.05	270	154.0	.06	35	3	90	148	.96	39
June 11	Sta 4 Bottom	102.0	.11	1.7	.02	260	124.4	.96	42	13	98	146	.96	36
June 11	Sta 6 Top	86.8	.16	1.9	.02	230	173.7	1.98	125	36	106	142	.96	36
June 11	Sta 6 Bottom	95.2	.15	2.1	.02	260	112.6	.97	67	22	92	148	.96	36
June 14	9A	103.4	< .05	4.0	.03	380	250.3	.20	207	32	158	224	2.13	103
June 15	Little River	126.0	< .05	6.5	.03	290	197.4	.06	190	29	130	188	2.13	36
June 20	Sta 18 Top	88.6	.10	2.4	.02	240	117.0	.70	84	37	90	128	.35	38
June 23	River 3	121.8	.06	9.0	.05	380	291.6	.18	348	41	138	240	.96	72
July 6	Sta 3 Top	102.8	< .05	2.5	.04	270	107.7	.05	18	3	94	152	.46	37
July 6	Sta 3 Bottom	101.0	< .05	2.7	.05	250	111.2	.07	35	2	98	140	1.45	37
July 17	Sta 3	99.3	< .05	2.8	.06	250	130.9	.15	42	5	98	146	.96	39
July 31	Sta 3	100.6	< .05	3.0	.02	240	191.7	.14	42	10	102	144	.96	38
July 31	Sta 6A	86.3	.75	3.3	.02	230	279.0	4.15	38	175	100	128	1.45	42
July 31	Sta 9A	112.1	< .05	2.7	.03	300	315.8	.20	57	15	114	184	1.45	47
July 31	Small River	124.0	< .05	3.9	.02	280	299.3	.22	100	19	116	160	.96	36
Aug 1	Sta 26	103.7	< .05	3.0	.02	250	348.3	.12	50	11	96	144	1.45	37
Aug 1	Sta 28	105.6	< .05	3.0	.02	280	334.7	.11	50	7	106	148	.46	38
Aug 1	Sta 29	106.6	< .05	3.8	.02	280	386.7	.09	80	11	114	164	1.45	40
Aug 1	Sta 30	109.7	< .05	3.5	.02	270	304.2	.12	63	14	114	148	1.93	41
Aug 1	River 1	160.3	< .05	10.0	.03	360	-	.14	350	45	164	184	5.35	36
Aug 1	River 2	157.6	< .05	4.6	.02	360	362.9	.10	125	15	143	196	.46	24
Aug 1	River 3	118.3	< .05	6.0	.03	310	386.9	.11	138	18	128	184	.46	46
Aug 2	Sta 18	87.4	.70	4.0	.02	250	167.6	4.24	448	130	106	140	1.45	30
Aug 2	Sta 21	99.0	.10	3.7	.02	250	269.5	.80	100	33	96	144	2.41	42
Aug 4	Tathlina L Site 1	130.0	< .05	2.5	.03	300	145.2	.15	120	21	128	160	1.95	33
Aug 4	Tathlina L Site 2	124.0	< .05	2.2	.02	300	299.1	.11	108	12	106	164	1.95	33
Aug 4	Tathl. L Freddy's R.	147.8	< .05	3.0	.02	360	337.1	.32	125	28	162	192	3.90	42
Aug 4	Tathlina L Site 4	117.7	< .05	2.2	.02	300	309.3	.50	135	28	118	180	1.45	41
Aug 31	Sta 3	98.8	< .05	3.5	.05	260	197.4	.22	35	7	98	140	1.45	40
Sept 4	Sta 3	109.8	< .05	4.0	.04	280	176.6	.65	84	8	120	146	1.45	42

APPENDIX II

TEMPERATURE AND DISSOLVED OXYGEN REGIMES IN KAKISA LAKE, N.W.T.

by

W.A. Fuller and R.J. Lambureux [1]

ABSTRACT

An environmental study of broad scope was undertaken on Kakisa Lake, N.W.T. It was found that the total water column responded very rapidly to physical factors in the environment. Dissolved oxygen levels remained near saturation throughout the year. Oxygen consumption by bacteria, bottom organisms and fish during the 8-month winter period appeared extremely low.

Dissolved oxygen levels and temperatures were very uniform throughout the water column on most days. This was mostly attributed to physical characteristics of the lake which promote wind agitation of the entire water column.

Phytoplankton was considered as possibly important in maintaining high oxygen levels in the lake. Decay of organic material was the principle reason put forward for several observed deviations from the normal super-saturated conditions in the lake.

Winter temperature profiles indicated a simple temperature gradient of 0.8°C per meter from top to bottom. There was no evidence for the existence in winter of a large stable 4°C water mass. Strong temperature gradients were associated with rapid warming from cooler temperatures. These gradients were easily broken down by wind action.

Water temperatures quickly followed ambient temperatures. Wind-mixing was postulated as a mechanism of heat transfer. High turbidity and long summer days were also likely causes for the rapid temperature changes with season and the high summer temperatures.

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INTRODUCTION

Early this year we were asked by Northern Canada Power Commission to undertake an environmental study of Kakisa Lake, NWT. This study was part of an overall feasibility study concerning possible future development of hydro-electric potential on the outlet river from Kakisa Lake.

We would like to thank Mr. Lowe of N.C.P.C. for allowing us to present a paper at this seminar prior to the release of the final environmental report.

DESCRIPTION AND LOCATION OF KAKISA LAKE

Kakisa Lake (Fig. 1) interrupts the flow of the Kakisa River about 15 miles south of its discharge point in a broad part of the Mackenzie River known as Beaver Lake. It is a large, shallow lake, with a maximum length of 24 miles, a maximum width of 8 miles, a maximum depth of 20 feet, and an average depth of 12-14 feet.

The lake is somewhat sausage-shaped and the shoreline is very regular. The long axis of the lake is oriented in a southeast-northwest direction, which will henceforth be called east-west to avoid confusion. The only major relief is provided by an escarpment which follows the south shore of the lake. The remainder of the terrain surrounding the lake is flat and poorly drained. Beach-ridges, 4 to 20 feet high, were found around most of the lake. However, the western end of the lake merges into a sedge bog, and there are no beach-ridges. Rooted aquatics are locally abundant, but are not found on more than 15 percent of the areal surface of the lake. There are six major inlet streams and one outlet stream.

METHODS AND MATERIALS

It was possible to carry out a four-season study in seven months, by commencing in mid-March (2 1/2 months before spring breakup) and finishing at freezeup in mid-October. The study was very broad in scope, since all aspects of the environment, both aquatic and terrestrial, required careful consideration.

To avoid the complications of developing new techniques, only very basic, time-tested techniques were employed. Limnological and fisheries work was carried out with standard equipment, such as Ekman dredge, Wisconsin plankton net and nylon gillnets. Sonar was used to good advantage for sounding. Temperatures were taken with a Applied Research ET100 Telethermometer. Dissolved oxygen was determined by the Alsterberg (azide) modification of the Winkler method. A great deal of general environmental data was gathered by direct observation, collection and air photo interpretation.

Limnological information was gathered at stations distributed around the lake during four major sampling periods: pre-breakup, early summer, mid-summer and pre-freezeup. In addition, data was gathered at more frequent intervals at Station P (Fig. 1).

Data presented in Figs. 2, 3, 4 and 6 are synthesized from data from widespread stations sampled infrequently as well as from station P which was sampled frequently. This is justified by the fact that data collected on a given day at widely separated locations were always quite homogeneous.

RESULTS

Dissolved Oxygen

Dissolved oxygen measurements were made in two of the inlet streams and in the lake proper prior to spring breakup. At the locations tested, both streams were anaerobic, with H_2S levels of from 3-5 ppm.

Late winter dissolved oxygen levels in the lake proper, however, ranged from 11.0 to 14.2 ppm. Percent saturation ranged from 78 percent to 105 percent.

Dissolved oxygen levels (Fig. 2) at various times of the year ranged from 14.2 under the ice to 8.1 in late July. Percent saturation (Fig. 3) ranged from 87 percent to 122 percent. It should be noted that maximum levels of dissolved oxygen expressed as ppm do not necessarily coincide with maximum levels expressed as percent saturation, since saturation levels are temperature dependent.

Saturation levels were above 100 percent most of the year, except during a brief period just after breakup, during the latter part of July, and during the fall cooling-off period.

Only on August 11 was there a significant difference in dissolved oxygen (1.1 ppm) between top and bottom of the water column. This was during a period of ambient temperature fluctuation, which caused an abnormally strong thermal gradient in the water column. At all other times, differences between top and bottom dissolved oxygen levels (in ppm) were well within the limits of error of the Winkler method.

Temperatures

Fig. 4 reveals that Kakisa Lake warmed up very rapidly in the spring, reached high (17°C - 19°C) and stable summer temperatures, and cooled off very quickly in the fall. Water temperatures followed ambient temperatures with very little lag.

Change from full ice cover to summer conditions of 17°C took approximately three weeks. The summer period lasted about 2 1/2 months until September 1. Rapid cooling of the water then took place, so that the total water column was at maximum density at 4°C by September 26. After that date, it was theoretically possible for an ice sheet to form over night. Actual freezeup occurred on October 10. This ice sheet was still intact when the project was abandoned October 14. Local residents told us that permanent ice sheets normally did not form until the end of the month.

Stable temperature gradients occurred only during winter (Fig. 5). There is no strong evidence for the existence of large stable masses of dense 4°C water. The only evidence for such a water mass occurred at Station 5, where temperature stabilized at 4°C from 3.5 m to the bottom at 4.3 m. In more typical cases, there is a steady gradient of about 0.8°C per meter from top to bottom.

Marked differences in temperature from top to bottom of the water column were principally associated with spring breakup (Fig. 6). Even during this time, however, the strong thermal gradients that developed were frequently broken down as the temperature of the water increased. During the remainder of the ice-free period, temperatures were very uniform throughout the water column, except on August 11 when the temperature difference from top to bottom was 2.1°C.

DISCUSSION

The winter anaerobic conditions found in the two streams investigated appear to be the result of low gradient, low flow, high summer organic production and total winter ice cover. It appears that all inlet streams, excluding the Kakisa River are similarly winter anaerobic, the properties on these other streams being even more conducive to anaerobic conditions.

A large proportion of the temperature and dissolved oxygen phenomena reported for the lake proper could be attributed to five physical factors which dominate this particular environment.

1. The lake is shallow for its size.

2. High wind exposure results from the very low relief on three sides of the lake.

3. The long axis of the lake is oriented in a northwest-southeast direction. Hence, the lake receives maximum exposure to the most frequently occurring winds.

4. The large areal extent of the lake increases wind exposure and influences local weather patterns by causing onshore-offshore winds.

5. Solar radiation is very intense and of long duration during the

long summer days.

It appears that factors 1 to 4 result in very thorough agitation of the entire water column throughout the ice-free period. This is likely the principle cause of the very high and uniform dissolved oxygen levels throughout the water column. In addition, it appears that phytoplankton could play an important role in keeping dissolved oxygen levels high. Because of the long summer days, the period of active photosynthesis is approximately three times longer than the period of night respiration at the time of the summer solstice. It is quite possible that the high degrees of supersaturation occurring in early and late summer could be due to plankton blooms. The mid-summer low could be due to a phytoplankton die-off. These speculations have not as yet been verified although a phytoplankton bloom was observed in mid-August.

The sharp drop and slow rate of recovery of dissolved oxygen levels after mid-August is very likely due to very intense bacterial decomposition of dead plant material. Organic material is uniformly spread through the water column by wave action, resulting in probable high rates of decomposition and little organic buildup in the sediments.

Freezeup occurred this year at approximately 95 percent oxygen saturation. It does not seem unreasonable that supersaturation would have been quite possible, had the lake frozen over three weeks later, as it did the previous year. Nevertheless, the high dissolved oxygen levels recorded in the late winter under the ice seem to indicate virtually zero consumption of oxygen by bacteria, bottom organisms and fish. It is possible that the temperature gradients as shown in Fig. 6 are somewhat steeper in the very cold winter months resulting in water temperatures approaching 0°C and very depressed metabolic rates.

The five factors proposed as the causes of high and uniform dissolved oxygen levels also appear to have a major effect on temperature regimes in the lake.

Wind-mixing of the total water column appears to break down temperature gradients within a short period after their formation (Fig. 7). Strong temperature gradients are found only during periods of rapid warming from cooler temperatures, as happened in June and mid-August. Even these strong gradients are susceptible to wind action, as evidenced by the June data in Fig. 7. It would also appear that the rapid turnover of thermal gradients is a major contributing factor to the rapid rates of heat transfer observed to take place between the air and the water.

An incidental effect of constant agitation of the water column is the high turbidity and resultant low albedo of the water. This could greatly assist the rate of increase of water temperature in the spring. By the same token, it should reduce the rate of cooling in the fall.

Finally, we should not underestimate the effect of the long summer days in the north, causing rapid warming of the lake in spring and constant high temperatures during the summer.

In concluding, we should point out that the dominant characteristic of Kakisa Lake is the extremely rapid response of the total water column to physical factors in the environment. This results in high and uniform oxygen saturation levels throughout the year, high summer water temperatures, low winter water temperatures and very rapid changes in water temperatures with changes in season. Thus, the Kakisa Lake environment appears to be somewhat severe from the point of view of temperature but quite moderate from the point of view of dissolved oxygen.

OPEN DISCUSSION WITH QUESTIONS AND COMMENTS FROM THE FLOOR

Dean D. M. Ross, Chairman

* * *

Chairman: Are there plans for development in this lake?

R. Lamoureux: Yes, that was the premise for this study in the first place.

D.M. Ross: Are they going ahead with anything?

R. Lamoureux: Well, it's uncertain right now. These are basically data which we provided to help in making the decision. I really don't have any comment to make about that.

J.R. Nursall: My question really follows on what Dr. Ross just said. This is a pre-impoundment study that you have done. It is known where the impoundment might be made, where an actual dam might be built, is it known what variation might follow in lake levels?

R. Lamoureux: Yes, the idea is to put the impoundment and the storage for the power project on Kakisa Lake itself. The actual regulation point would be about 3 miles downstream at the outlet. Actually, this three-mile stretch of the river would be at the same level as the level of the lake. It appears at present that the fluctuations would not be particularly great, because of the topography of the region.

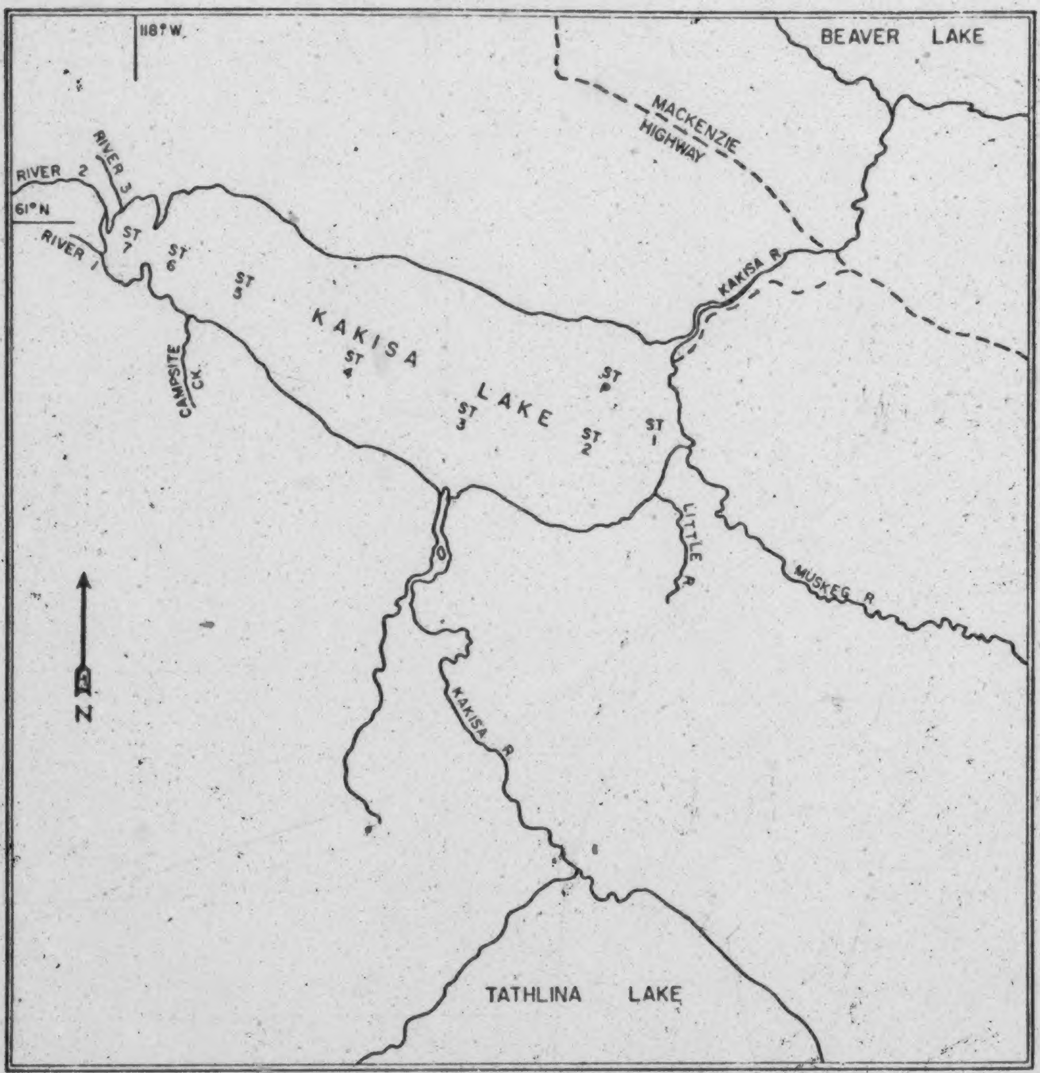
118° W.
BEAVER LAKE
MACKENZIE HIGHWAY
RIVER 3
RIVER 2
61° N
RIVER 1
ST 7
ST 6
ST 5
KAKISA LAKE
ST 4
CAMPSITE CK.
ST P
ST 3
ST 2
ST 1
KAKISA R.
LITTLE R.
MUSKEG R.
N
KAKISA R.
TATHLINA LAKE

Figure 1. Kakisa Lake Study Area. Coordinates are given in top left hand corner. Station numbers indicate locations of winter sampling locations. ST P denotes location of most frequently sampled summer lake station.

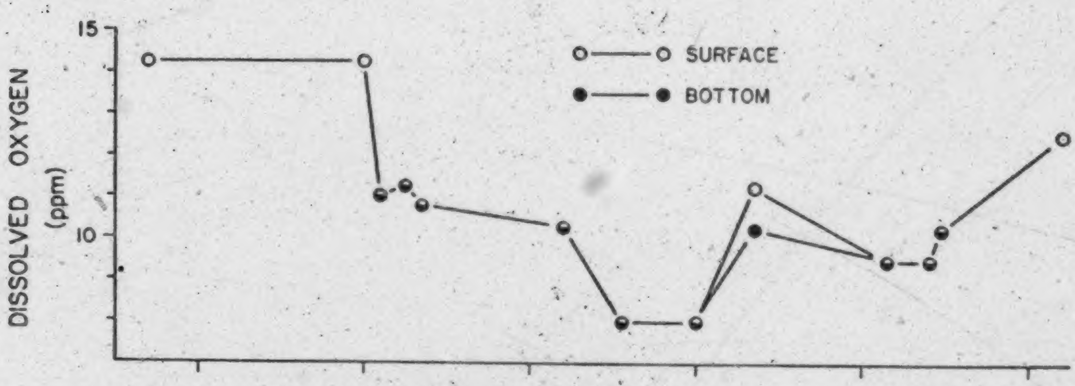

Figure 2. Absolute dissolved oxygen levels (ppm) from late April to mid-October. Late April value is beneath ice cover. Final October value is just prior to freeze-up.

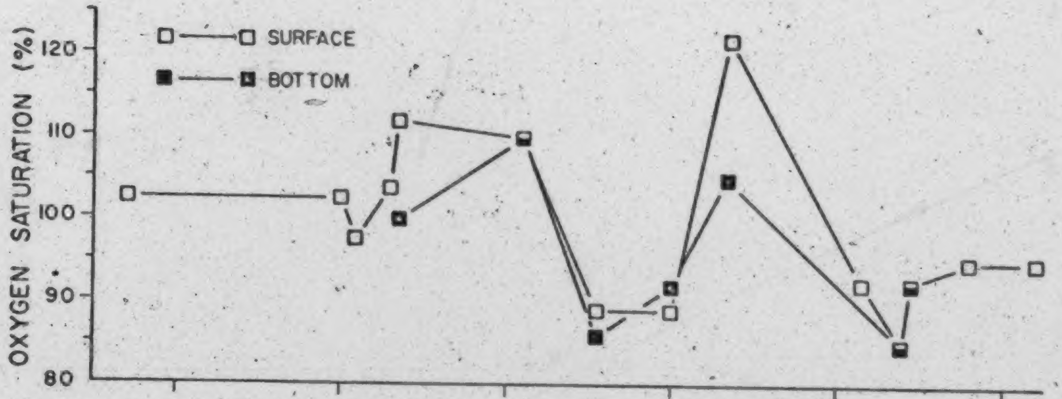

Figure 3. Percent saturation of dissolved oxygen from late April to mid-October.

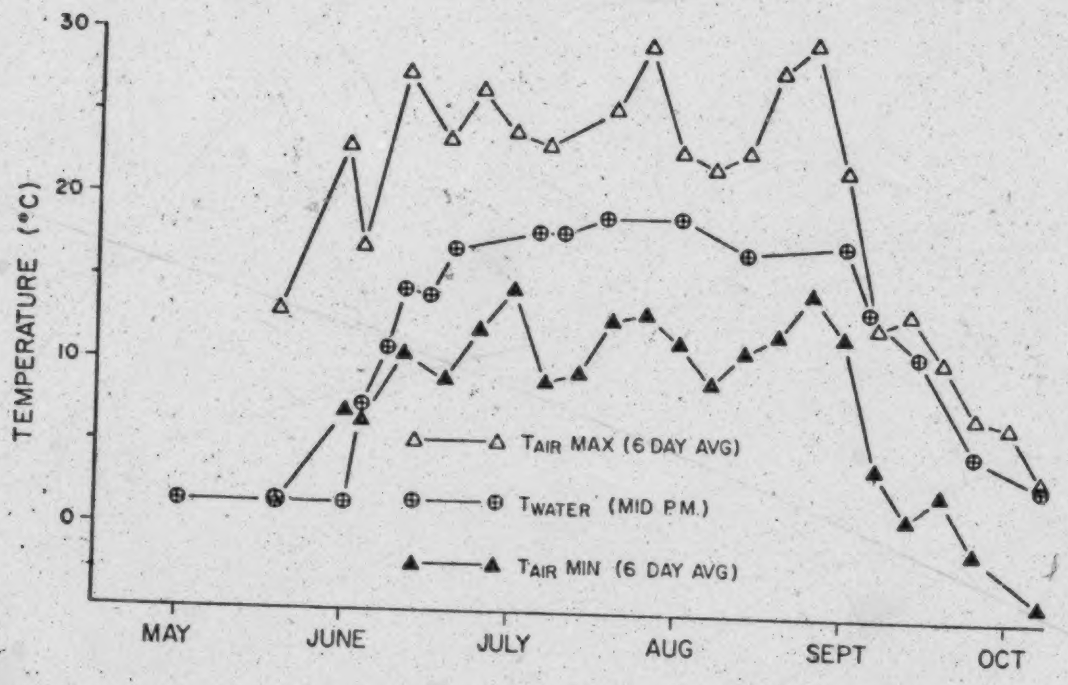

Figure 4. Minimum and maximum air temperatures and daytime water temperatures from May to October. Maximums and minimums are six-day averages. Water temperatures are point measurements or averages of point measurement normally taken in the mid-afternoon.

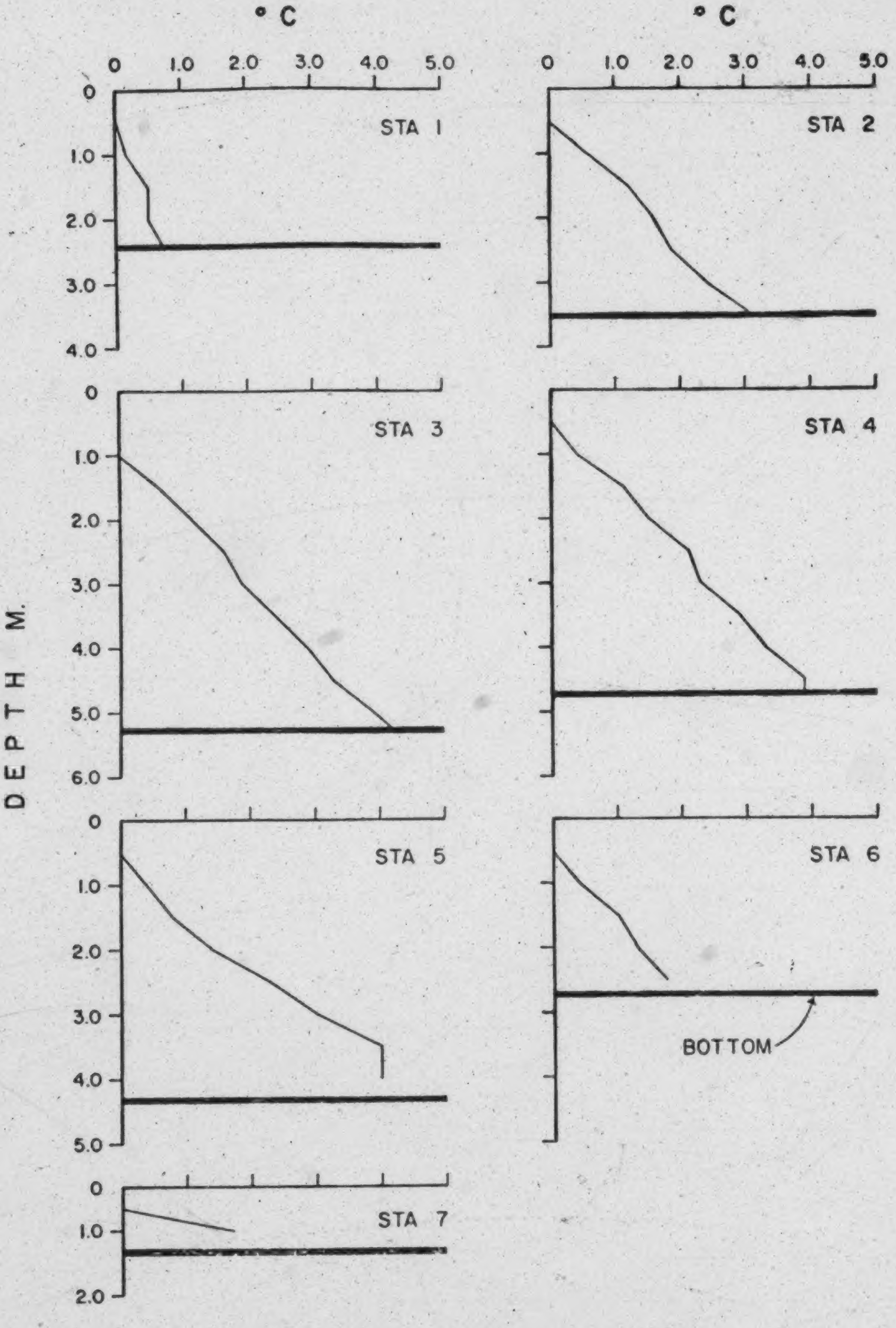

Figure 5. Winter Temperature Profiles, May 7, 1972.
(Location of stations is shown on Fig. 1.)

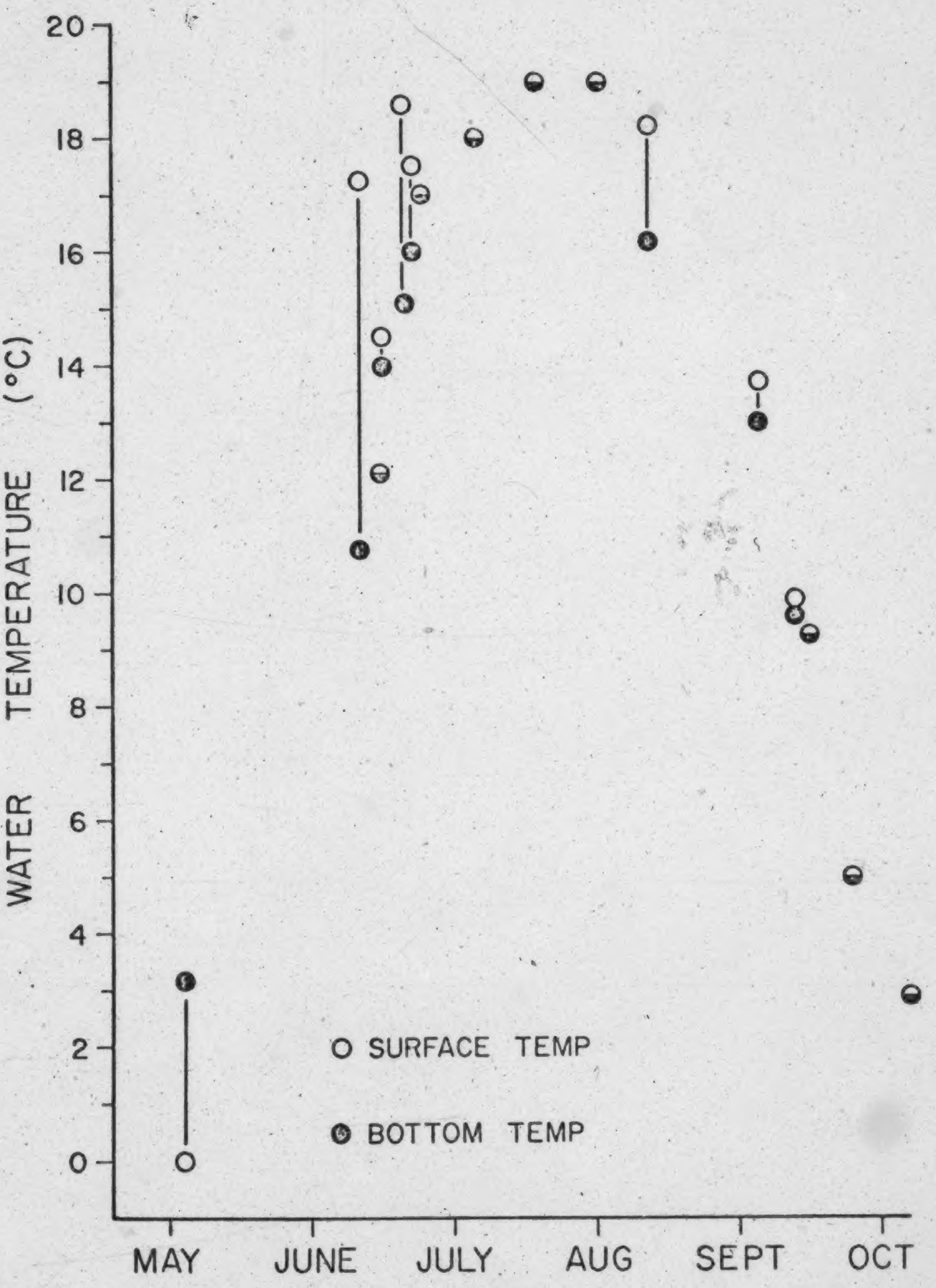

Figure 6. Surface and Bottom Temperatures, Kakisa Lake. Temperatures are usually averages of several point measurements taken during biological sampling runs.

APPENDIX III. Stomach contents of walleye (Tathlina River, spring, 1972)

Food organism	% of stomachs containing organism	Total number of organisms in all stomachs	Estimated weight (g)	% wt. of food in all stomachs
Trout-perch	78.5*	156	593	86.2
Unidentified fish	21.7	19	95	13.8
Fish material	100	175	688	≈100
Mayfly nymphs	1.7	1	0.1	≈0
Invertebrate material	1.7	1	0.1	≈0

*Of 60 fish with food in stomachs.

Catch data: Fish with empty stomachs 9 (13.1%)
Fish with food in stomachs 60 (86.9%)

APPENDIX III (continued). Stomach contents of walleye (minor inlet rivers, spring, 1972)

Food organism	% of stomachs containing organism	Total number of organisms in all stomachs	Estimated weight (g)	% wt. of food in all stomachs
Trout-perch	9.5*	2	7.6	6.8
Cisco	4.8	1	19.0	17.0
Walleye	4.8	1	5.0	4.5
Unidentified fish	66.7	16	80.0	71.4
Fish material	81.0	20	111.6	99.7
Mayfly nymphs	19.1	12	0.24	0.21
Mayfly adults	4.8	1	0.02	0.02
Chironomid larvae	9.5	20	0.02	0.02
Caddisfly larvae	9.5	2	0.02	0.02
Biting midge larvae	4.8	1	0.001	0.001
Invertebrate material	38.1	36	0.30	0.3

*Of 21 fish with food in stomachs

Catch data:	Fish with empty stomachs	32 (60.4%)
	Fish with food in stomachs	21 (39.6%)

APPENDIX III (continued). Stomach contents of walleye (Kakisa River, summer, 1972)

Food organism	% of stomachs containing organism	Total number of organisms in all stomachs	Estimated weight (g)	% wt. of food in all stomachs
Trout-perch	5.3*	6	22.8	22.3
Sticklebacks	26.3	8	4.8	4.7
Cisco	5.3	1	19.0	18.6
Unidentified fish	42.1	11	55.0	53.7
Fish material	79.0	26	101.6	99.3
Mayfly nymphs	21.0	4	0.08	0.08
Mayfly adults	10.5	2	0.04	0.04
Leeches	15.8	5	0.50	0.50
Scuds (amphipods)	10.5	2	0.04	0.04
Invertebrate material	47.4	13	0.66	0.7

*Of 19 fish with food in stomachs.

Catch data: Fish with empty stomachs 18 (48.6%)
Fish with food in stomachs 19 (51.4%)

APPENDIX III (continued). Stomach contents of walleye (open lake, summer, 1972)

Food organism	% of stomachs containing organism	Total number of organisms in all stomachs	Estimated weight (g)	% wt. of food in all stomachs
Sticklebacks	29.6*	57	34	7.3
Cisco	29.6	17	323	69.8
Unidentified fish	34.1	21	105	22.7
Fish material	91.0	95	462	99.8
Mayfly nymphs	15.9	7	0.70	0.15
Mayfly adults	2.3	1	0.10	0.02
Caddisfly adults	2.3	1	0.01	0.002
Biting madge larvae	2.3	1	0.001	0.0002
Leeches	2.3	1	0.10	0.02
Clams	2.3	1	0.01	0.002
Invertebrate material	20.4	12	0.92	0.02

*Of 44 fish with food in stomachs

Catch data:	Fish with empty stomachs	60 (57.7%)
	Fish with food in stomachs	44 (42.3%)

APPENDIX IV. Stomach contents of northern pike (Tathlina River, spring, 1972)

Food organism	% of stomachs containing organism	Total number of organisms in all stomachs	Estimated weight (g)	% wt. of food in all stomachs
Trout-perch	81.2*	107	407	92.1
Unidentified fish	25.0	7	35	7.9
Fish material	100	114	442	≈100
Caddisfly larvae	6.3	1	0.01	0.002
Invertebrate material	6.3	1	0.01	0.002

*Of 16 fish with food in stomachs

Catch data: Fish with empty stomachs 2 (11.1%)
Fish with food in stomachs 16 (88.9%)

APPENDIX IV (continued). Stomach contents of northern pike (minor inlet rivers, spring, 1972)

Food organism	% of stomachs containing organism	Total number of organisms in all stomachs	Estimated weight (g)	% wt. of food in all stomachs
Trout-perch	19.2*	11	41.8	30.1
Cisco	11.5	3	57.0	41.0
Walleye	7.7	1	5.0	3.6
White sucker	7.2	2	10.0	7.2
Unidentified fish	19.2	4	20.0	14.4
Fish material	55.7	21	133.8	96.3
Mayfly adults	3.8	1	.02	0.014
Caddisfly larvae	3.8	1	.01	0.007
Dragonfly larvae	19.2	16	1.60	1.15
Damselfly larvae	11.5	11	1.10	0.79
Beetle larvae	3.8	2	.20	0.14
Water bug adults	7.7	2	.02	0.014
Unidentified insects	3.8	1	.005	0.004
Scuds (amphipods) - large	15.4	98	1.96	1.41
Scuds (amphipods) - small	7.7	8	.04	0.029
Leeches	7.7	2	.20	0.14
Clams	3.8	1	.01	0.007
Invertebrate material	50.0	142	5.17	3.7

*Of 26 fish with food in stomachs

Catch data: Fish with empty stomachs 17 (39.5%)
Fish with food in stomachs 26 (60.5%)

APPENDIX IV (continued). Stomach contents of northern pike (Kakisa River, 1972)

Food organism	% of stomachs containing organism	Total number of organisms in all stomachs	Estimated weight (g)	% wt. of food in all stomachs
Sticklebacks	25.0*	24	14.4	13.0
Cisco	37.5	4	76.0	68.8
Walleye	12.5	2	10.0	9.1
Unidentified fish	25.0	2	10.0	9.1
Fish material	100	32	110.4	100

*Of 8 fish with food in stomachs.

Catch data: Fish with empty stomachs 6 (42.8%)
Fish with food in stomachs 8 (57.2%)

APPENDIX IV (continued). Stomach contents of northern pike (open lake, 1972)

Food organism	% of stomachs containing organism	Total number of organisms in all stomachs	Estimated weight (g)	% wt. of food in all stomachs
Trout-perch	12.7	9	34.2	3.6
Sticklebacks	12.7	42	25.2	2.6
Cisco	67.3	42	817.0	85.9
Burbot	3.6	2	10.0	1.1
Unidentified fish	20.0	13	65.0	6.8
Fish eggs	1.8	1	.01	0.001
Fish material	98.2	109 (+ 1 egg)	951.4	≈100
Mayfly nymphs	5.5	3	0.3	0.03
Invertebrate material	5.5	3	0.3	0.03

APPENDIX V. Stomach contents of lake cisco (Kakisa Lake, 1972)

Food organism	% of stomachs containing organism	Total number of organisms in all stomachs	Estimated weight (g)	% wt. of food in all stomachs
Cladocerans	84.2*	29,550	8.87	72.7
Copepods	73.7	31,000	3.10	25.4
Zooplankton	94.7	60,500	11.97	98.1
Mayfly nymphs	11.5	9	0.18	1.48
Chironomid larvae	5.3	8	0.008	0.07
Other dipteran larvae	2.6	3	0.003	0.02
Water bugs	2.6	1	0.01	0.08
Bettle larvae	2.6	1	0.01	0.08
Terrestrial insects	2.6	1	0.005	0.04
Fish eggs	2.6	1	0.01	0.08
Non-zooplankton	18.4	0.23	0.23	1.9

*Of 38 fish with food in stomachs.

Catch data: Fish with empty stomachs
Fish with food in stomachs

APPENDIX VI. Stomach contents of lake whitefish (open lake, 1972)

Food organism	% of stomachs containing organism	Total number of organisms in all stomachs	Estimated weight (g)	% wt. of food in all stomachs
Mayflies (mostly nymphs)	43.0	465	46.50	33.42
Caddisfly larvae	13.9	167	1.67	1.20
Chironomid larvae	10.1	41	0.041	0.03
Other dipterans (larvae & adults)	10.1	9	0.009	0.006
Water bugs	27.8	55	0.55	0.40
Bettle larvae	13.9	17	1.70	1.22
Terrestrial insects	10.1	52	0.26	0.19
Unidentified insects	7.6	11	0.055	0.04
Scuds (Amphipods)	11.4	482	2.41	1.73
Copepods	2.5	186	.019	0.01
Mites	3.8	4	.004	0.003
Leeches	1.3	1	.100	0.07
Snails	46.8	7370	73.70	52.97
Clams	29.1	199	1.99	1.43
Invertebrates (all species)	94.9	9059	129.01	92.7
Fish	3.8	3	1.80	1.29
Fish eggs	20.3	832	8.32	5.98
Fish (all species	24.1	832 (+ 3 eggs)	10.12	7.3

APPENDIX VI (continued). Stomach contents of lake whitefish, (Kakisa River (8 specimens), Muskeg River (37 specimens), Small River (9 specimens), Tathlina River (1 specimen), River 1 (8 specimens) 1972)

Food organism	% of stomachs containing organism	Total number of organisms in all stomachs	Estimated weight (g)	% wt. of food in all stomachs
Mayflies (mostly nymphs)	57.1*	2157	46.40	40.10
Caddisfly larvae	20.6	36	0.72	0.62
Chironomid larvae	60.3	1985	1.99	1.72
Other dipterans (larvae & adults)	34.9	125	.13	0.11
Damselfly nymphs	6.3	4	0.40	0.35
Water bugs	57.1	553	11.60	10.03
Beetle larvae	27.0	89	8.90	7.69
Terrestrial insects	15.9	112	.56	0.48
Unidentified insects	6.3	10	.05	0.04
Scuds (Amphipods)	33.3	666	11.01	9.52
Mysis	1.6	16	.32	0.27
Cladocerans	39.7	64000	19.20	16.59
Copepods	7.9	3050	.31	0.26
Ostracods	4.8	6	.002	.002
Mites	11.1	24	.024	.02
Snails	23.8	589	5.89	5.09
Clams	22.2	391	3.91	3.38
Invertebrates (all species)	100.0	73,813	111.40	96.30
Fish	4.8	7	4.20	3.63
Fish eggs	1.6	10	.10	.09
Fish (all species)	6.3	7 (+ 10 eggs)	4.30	3.70

Catch data: Fish with empty stomachs 5 (7.4)
Fish with food in stomachs 63 (92.6%)

*Of 63 fish with food in stomachs.

APPENDIX VII. Stomach contents of white suckers (Muskeg River (30 specimens), Little River (6 specimens), Tathlina River (13 specimens), and Open Lake (1 specimen), 1972)

Food organism	% of stomachs containing organism	Total number of organisms in all stomachs	Estimated weight (g)	% wt. of food in all stomachs
Mayfly nymphs - large	10.8*	74	7.40	29.3
Mayfly nymphs - small	54.0	289	5.78	22.8
Caddisfly larvae	48.6	46	.46	1.8
Stonefly nymphs	2.7	1	.10	0.4
Chironomid larvae	73.0	2829	2.83	11.2
Other dipterans (mostly larvae)	27.0	117	.12	0.4
Dragonfly nymphs	2.8	1	.10	0.4
Damselfly nymphs	8.1	8	.80	3.2
Water bugs	35.1	41	.41	1.6
Bettle larvae (+ 1 adult)	13.5	6	.60	2.4
Terrestrial insects	8.1	6	.03	0.1
Unidentified insects	5.4	2	.01	0.04
Scuds (Amphipods) - large	5.4	77	1.54	6.1
Scuds (Amphipods) - small	13.5	59	.30	1.2
Cladocerans	13.5	1900	.57	2.2
Mites	5.4	2	.002	0.01
Snails	54.1	155	1.55	6.1
Clams	37.8	127	1.27	5.0
Fish eggs	8.1	143	1.43	5.7
All material	100	3413 (+142 eggs)	25.30	100.0

*Of 37 fish with food in stomachs

Catch data:		
	Fish with empty stomachs	13 (26%)
	Fish with food in stomachs	37 (74%)

APPENDIX VIII. Age - size data for walleye from Kakisa Lake (F.R.B., 1968)

Growth parameters	Age										
	1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+
Fork length (cm)											
Sample size		1	3	12	7	12	16	17	17	14	
Range			11.6 to 17.5	19.5 to 26.5	23.0 to 34.5	27.5 to 36.0	30.5 to 39.0	32.5 to 42.0	34.5 to 45.3	36.5 to 54.5	
Mean		16.5	15.8	21.9	27.2	32.6	35.0	36.9	40.3	41.0	
Weight (g)											
Sample size		1	3	12	7	12	16	17	17	14	
Range			45.0 to 91.0	45 to 183	136 to 545	227 to 454	272 to 636	227 to 772	590 to 1135	499 to 1771	
Mean		45	76	113	286	416	471	555	750	807	

APPENDIX IX. Age - size data for northern pike from Kakisa Lake (F.R.B., 1968)

Growth parameters	Age										
	1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+
Fork length (cm)											
Sample size	3	3	13	19	9	11	2				
Range	27.0 to 32.0	36.0 to 41.0	40.5 to 49.5	41.0 to 55.7	44.0 to 60.8	50.0 to 62.3	58.0 to 65.0				
Mean	29.5	37.9	45.8	48.0	51.7	56.0	61.5				
Weight (g)											
Sample size	3	3	13	17	8	11	2				
Range	182 to 227	363 to 545	454 to 772	499 to 1090	590 to 1362	681 to 1544	1362 to 2315				
Mean	212	469	668	750	897	1086	1839				

APPENDIX X. Age - size data for whitefish from Kakisa Lake (F.R.B., 1968)

Growth parameters	Age 1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+
Fork length (cm)											
Sample size		2	23	3	4	10	7	9	14	8	3
Range		14.5 to 19.0	16.0 to 22.0	23.7 to 26.2	21.0 to 32.0	30.5 to 41.5	32.5 to 41.5	32.5 to 38.5	37.7 to 43.0	37.5 to 41.0	40.4 to 44.0
Mean		16.75	19.5	25.0	28.0	33.9	35.3	36.4	39.3	39.5	43.3
Weight (g)											
Sample size		1	15	2	3	8	6	9	13	6	3
Range			45 to 227	227 to 318	227 to 499	409 to 772	545 to 863	363 to 817	590 to 1226	908 to 1135	999 to 1180
Mean		182	105	272	393	590	696	706	932	1006	1074

APPENDIX XI. Age - size data for white suckers from Kakisa Lake (F.R.B., 1968)

Growth parameters	Age										
	1+	2+	3+	4+	5+	6+	7+	8+	9+	10+	11+
Fork length (cm)											
Sample size			1	1	14	33	7	1			
Range					21.7 to 40.0	30.1 to 46.5	37.5 to 46.0				
Mean			24.5	25.6	31.6	40.4	41.2	43.0			
Weight (g)											
Sample size					12	33	7	1			
Range					272 to 1090	772 to 1498	817 to 1498				
Mean					773	1091	1128	1180			